Essays on international trade and the environment

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PROEFSCHRIFT

ter verkrijging van de graad van doctor aan de Universiteit van Tilburg, op gezag van de rector magnificus, prof. dr. Ph. Eijlander, in het openbaar te verdedigen ten overstaan van een door het college voor promoties aangewezen commissie in de aula van de Universiteit op woensdag 1 juni 2011 om 14.15 uur door

CHRISTIAN WILLEM JOHAN BOGMANS,

geboren op 30 december 1981 te Eindhoven.

PROMOTORES: prof.dr. C.A.A.M. Withagen
prof.dr. J.A. Smulders

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Contents

Chapter 1

Introduction

1.1 Background

1.1.1 History

A short history of academic research on trade and the environment begins in the 1970s, when several OECD countries took measures to limit air and water pollution. Prominent examples of environmental laws in the United States that were initiated or strengthened during that period are the Clean Water Act and the Clean Air Act. These measures led to the belief that environmental regulations could alter existing patterns of trade and, if regulations would be too stringent, industries might relocate to countries where environmental regulations were weak. Most work in this period was concerned with issues related to optimal trade and environmental policies.

During the 1990s the research focus shifted towards a more thorough understanding of the positive aspect of trade and the environment. In this decade some new topics emerged as well, e.g. (i) strategic environmental policy in open economies and (ii) international trade in renewable resources, which nowadays constitute an important set of topics within the field. Academic research during the 1990s was also inspired by policy debates on the virtues of free trade, in which the anti-globalization movement played a pivotal role by increasing public interest, and the fear of environmental degradation following the formation of the North American Free Trade Agreement (NAFTA). Supporters of the anti-globalization movement believed that expansion of free markets would eventually lead to widespread environmental degradation.

Among recent interests in the field are such topics as (i) international trade and climate change and (ii) the relationship between food, environment and energy.

1.1.2 Why Trade and the Environment?

The reasons for studying the relationship between international trade and the environment are threefold. First and foremost, trade affects cross-country patterns of production and consumption. If (activities related to) production and consumption have an impact on the environment, then by extension trade will affect the environment as well (Sheldon, 2006). Policies aimed at controlling the negative externalities of production and consumption will then indirectly, by influencing factor returns and commodity prices, also change the pattern of trade. Second, trade itself has a direct impact on the environment via emissions generated by (long-distance) transportation and negative externalities that are related to the problem of invasive species. Surprisingly, there is still little attention for the more direct effects of trade on the environment (McAusland, 2008). The effects of trade on the environment can thus be categorized as both direct and indirect. Third and finally, international trade constitutes an important pillar of capitalism. As such, public interest with respect to the vice and virtues of capitalism often centers on the role of international trade. In this context free trade has been subject to criticism by the anti-globalization movement since allegedly the link between free trade and the environment is a negative one.

1.1.3 Trade and the Environment: the Pollution Haven Hypothesis

Understanding the relationship between trade and the environment requires basic knowledge of the interdependence between the economy and the environment. On a global level economic activity is part of, and takes place within, the system which is the earth and its atmosphere (Perman et al.(2003)). In the past, the scope and size of economic activity compared to its wider environment, the earth, seemed tiny and therefore any analysis of economic activity could do without this broader perspective. This view changed throughout the 20th century. It became apparent that it was no longer sufficient to look at economic activities in isolation when the stress induced by these activities on the wider environment, in terms of material inputs used, pollution discharged and waste disposed, seemed to have increased up to a point where limiting factors come into play.

Economists and environmental scientists differentiate between four basic interdependencies between economic activity on the one hand and the environment on the other hand, which are best understood in isolation. First, human economic activity requires material inputs for production (i.e. raw materials and minerals as inputs in manufacturing processes, fossil fuels for combustion). Second, activities related to production and consumption lead to the disposal of various forms of waste residuals into the natural environment. Third, human consumption benefits from amenity services for recreational purposes (i.e. wilderness and beach recreation). Fourth and finally, the biosphere provides for basic life-support functions (i.e. various planet-wide regulation systems that keep the Earth's climate within a zone that is suited for life).

Economists have gone even further in simplifying the relationship between economic activity and the environment. Many studies in the field of environmental and resource economics, including those on trade and the environment, treat the environment as the second or third factor of production, next to labor and capital. A country is said to be environmentally abundant if (i) it has a large assimilative capacity for pollution (Dean, 1992), (ii) if it is abundant in natural resources, e.g. land and minerals, or (iii) if it is characterized by weak environmental policy.

Early studies that examined the linkage between patterns of trade, environmental pollution and comparative advantage are Siebert (1977, 1985) and Pethig (1976). These authors used simple trade models, based on Ricardian trade theory or specific factors theory, assumed countries differed only in terms of exogenously given stringency of environmental policy, and concluded that the country with weaker environmental policy would be an exporter of the pollution-intensive commodity. Perhaps, these studies were the first to investigate the so-called pollution haven hypothesis (PHH), which states that under trade liberalization dirty industries will relocate from high-income countries with stringent environmental regulation to low-income countries with weak or non-existent environmental regulation (Taylor, 2005).

Copeland and Taylor (1994) have built a very influential pollution haven model, based on the Ricardian trade model of Dornbusch, Fisher and Samuelson (1977). Compared to previous studies, Copeland and Taylor (1994) were the first to connect cross-country differences in income-induced environmental regulations to predictions on trade patterns and pollution. They consider a world economy consisting of two countries, North and South, with a continuum of commodities, produced using labor and emissions, and ranked according to emission intensity. Abatement of pollution is possible and requires the use of a fraction of gross output. The analysis rests on two assumptions. First, the two countries are assumed to differ only in terms of effective labor supply, which can be interpreted as a difference in the average level of human capital. Second, environmental quality is assumed to be a normal good. In each country, a social planner is concerned with the trade-off between more pollution, which leads to a higher level of real income, and the environmental damage associated with more pollution. Starting from these assumptions, they find that the optimal tax on emissions is increasing with the level of income. In equilibrium the high-income country will specialize in the production of human-capital intensive goods whereas the low-income country specializes in the production of pollution-intensive goods. Furthermore, a shift from autarky to trade will increase (decrease) emission in the country with lax (stringent) regulation. Global pollution always increases under free trade. Since pollution policies are optimal, both countries gain from trade although green welfare diminishes (Taylor, 2005).

1.1.4 The Pollution Haven Hypothesis: Empirics

Testing for the pollution haven hypothesis and finding convincing evidence has turned out to be a challenging endeavour. Much of the empirical literature prior to 1997 considered the relationship between trade flows, investment flows and environmental regulations using cross-sectional data (see Ederington (2010) and Copeland and Taylor (2004)). The consensus emerging from these studies seems to be that there is no significant correlation between environmental regulation on the one hand and trade flows on the other hand.

These early studies were subject to several related critiques. First, many papers were short on theory so empirical results would lend themselves to different interpretations. This becomes evident when one realizes that pollution, income and trade flows are all simultaneously determined in general equilibrium models. Any empirical method of estimation that investigates a single relationship in isolation, say between regulation and trade flows, ignores the fact that both regulation and trade flows are endogenously determined. Second, failure to find empirical evidence does not prove theory is wrong altogether. For example, some have argued that the most important determinants of comparative advantage in dirty commodities are not related to differences in environmental policy, but to differences in factor endowments and technology. As such, this explanation leaves ample room for the so-called pollution haven effect, which states that income-induced differences in environmental policy will affect trade flows at the margin. Third, cross-country studies are unable to correct for unobserved heterogeneity across industries and the endogeneity of abatement costs. These problems can be accounted for by using panel data and instrumental variables techniques. Incorporating these critiques, there now exists an extensive literature that documents a relationship between environmental regulation and several measures of trade and industrial activity (see Ederington (2010)).

Scant empirical evidence for the pollution haven hypothesis has also forced researchers to consider alternative explanations. One of these explanations rests on the idea that pollution haven effects identify just one out of many factors that influence the location of dirty industries. In this context it has been argued that many OECD countries are characterized by stringent environmental regulation yet appear to be net exporters in many pollution intensive industries. As it turns out, capital-intensity and emission-intensity are often strongly correlated, which suggests that capital abundance plays a large role in the determination of location patterns of pollution intensive industries as well. This observation has led to the construction of theories that incorporate both pollution haven arguments as well as more intricate factor endowment considerations. The factor endowment hypothesis states that under trade liberalization dirty industries will relocate from poor, capital-scarce countries to rich, capital-abundant countries. Copeland and Taylor (2003) build a model that incorporates both the pollution haven argument and the factor endowment argument and find that the relative strength of these two opposing forces will determine the pattern of trade and the location of dirty industries. Antweiler, Copeland and Taylor (2001) use sulfur dioxide data from the Global Environment Monitoring System (GEMS) from 290 sites in 108 cities representing 43 countries and spanning the period 1971-1996 to test for the determinants of average SO2 concentrations at each site. Their results suggest that the influence of capital abundance on comparative advantage overwhelms the income-induced policy effect.

1.1.5 Trade, Growth and the Environment

The main argument in favor of trade is that it raises real income. In turn, changes in real income are expected to have an impact on environmental quality. Therefore, and closely related to the previous literature, various scholars have studied the relationship between trade and the environment in the wider context of a "trade-growth-environment triangle".

A series of influential papers by Grossman and Krueger (1993, 1995) have shown that there exists an U-shaped relationship between income and environmental quality, which later has become known as the environmental Kuznets curve. Using data on air quality and water quality for a large number of countries, Grossman and Krueger (1995) find that environmental quality first tends to worsen when income per capita increases, but then improves once income per capita reaches a certain intermediate level of income per capita. The technical apparatus to understand more clearly the various effects of growth on environmental quality was developed by Grossman and Krueger (1993) and Copeland and Taylor (1994). These studies introduced and formalized the concepts of scale, composition and technique effects. The scale effect measures the increase of pollution by scaling up current economic activity, without changing the composition of a country's output or production techniques. If we hold the size of the economy constant, but devote more resources to the production of dirty commodities, then pollution increases as well. We define this as the composition effect. Finally, there is a so-called technique effect. Keeping scale and composition constant, it is possible to decrease pollution by using production techniques with a lower emission intensity.

This decomposition of changes in economic activity and its environmental impact has proved to be a useful tool in both empirical and theoretical work. For example, one can apply this terminology to describe the environmental Kuznets in more detail. The detrimental scale effect is most important for lower levels of income, inducing higher levels of pollution. Once the demand for environmental quality has risen sufficiently, economic transformation towards cleaner sectors (composition effect) and the adoption of novel abatement technologies (technique effect) will outweigh the scale effect, and emissions will go down. On the empirical front, theory has guided empirical work in new directions and helped researchers to ask the right questions. For example, Levinson (2009) asks how much of the overall pollution reduction in US manufacturing over the past decades comes from technology and how much comes from changed patterns of international trade. He finds that the technique effect has been by far the most important contributor to the clean-up of the manufacturing industry. Trade only played a minor role in the composition shift away from dirty industries, and that composition effect was far less important than the technique effect.

1.1.6 Trade and Environmental Policies: A Race to the Bottom?

Research on (i) linkages between environmental policy and the emergence of pollution havens and (ii) the environmental Kuznets curve has produced several interesting results and hypothesis'. Many of these are primarily cast in positive terms, i.e. they relate country characteristics to environmental quality and patterns of trade, whereas welfare considerations play a minor role. For example, the pollution haven hypothesis itself is silent on the implications of trade liberalization for (global) welfare. Another major approach to the field of trade and the environment has been to consider trade from a strategic perspective. Efforts in this area have led to a body of work that often has a more normative character, i.e. results obtained here are stated in terms of their implications for welfare.

This game-theory oriented approach has adopted models based on imperfect competition, mostly situated in a partial equilibrium setting. Welfare-maximizing governments decide non-cooperatively on the stringency of their environmental (and trade) policies. Early contributions to this literature are Rauscher (1991), Conrad (1993), Barret (1994) and Kennedy (1994). Most of these papers consider strategic interaction in a framework in which polluting firms from two different countries compete for consumers in a third country. Governments have an incentive to act strategically by using domestic environmental policy to raise the competitiveness of domestic firms in international markets, thereby allowing these firms to capture a larger share of profits. Thus, governments have an incentive to not only use environmental policies to protect the environment, but also to raise producer surplus by shifting rents. This phenomenon has become known as ecological dumping. Since both countries face similar incentives, ecological dumping might lead to a so-called race-to-the-bottom where Nash equilibrium policies will be set below their Pigouvian levels. In the non-cooperative equilibrium there is underprovision of environmental quality and welfare in each country is lower than in the first-best, provided countries are sufficiently symmetric. Kennedy (1994) explains that the possibility of a race-to-the-bottom is even stronger under transboundary pollution. The reason for this is that with transboundary pollution the not-in-my-back-yard (NIMBY) motive disappears: the location of production has become irrelevant with respect to the local environmental damages that it causes. Therefore, countries have a reduced incentive to lower domestic pollution.

The use of environmental policies to attain trade-related objectives, e.g. increasing competitiveness of domestic firms, is based on the premise that governments are no longer allowed to use trade-policy instruments, e.g. tariffs and quotas. Under the guidance of the World Trade Organization (WTO) world trade has been growing rapidly over the last few decades and in line with the current regulatory framework of the WTO, the General Agreements on Tariffs and Trade (GATT), all member countries are, to an increasing extent, prohibited from using trade restrictions. The focus on a race-to-the-bottom is therefore not merely a theoretical curiosity, but relevant in a world where trade barriers are progressively declining, leaving governments with no clear alternative of raising welfare except the (ab)use of domestic policies. The tariff-substitution argument has led to several proposals on how the WTO should deal with environmental policies, which could eventually result in a set of binding minimum standards. In this context, complete harmonization clearly cannot be efficient. For example, for the case of greenhouse gas emissions an efficient reduction in emissions would imply equalization of the marginal costs of abatement across countries which would most likely be hampered by full harmonization. It has also been argued that the tariff-substitution argument could be dealt with by linking trade agreements and environmental agreements, or allowing for punishment schemes that involve trade measures for countries that do not comply with certain environmental standards. Whether such linkages could be effective in limiting environmental degradation is an unresolved issue.

1.1.7 Trade in Renewable Resources

Though pollution problems form an important part of the research agenda in the aforementioned literature, environmental economists have also paid much attention to problems related to renewable resources[1]. Parallel to the literature on trade and pollution, a distinct body of work has emerged on trade and renewable resources. Important examples of renewable resources include forests, fisheries and wildlife (e.g. elephants, tigers, gorillas). Renewable resources pose a different challenge to economists due to their dynamic nature: they may be depleted because of harvesting activities, but have the opportunity to regenerate thanks to biological processes. Like problems related to trade and environmental pollution, weak policies can lead to too much harvesting. In addition, the dynamics associated with renewable resources introduce a whole new set of issues. Weak institutions can lead to the problem of "open access", where firms and individuals extract resources without taking into account the repercussions for other resource users or future resource stocks. This problem has been coined "the tragedy of the commons" (see Hardin (1968)).

Trade provides for interesting insights into the tragedy of the commons and other problems related

[1]This section closely follows the overview on trade and renewable resources by Fischer (2010).

to renewable resource use. First and foremost, trade liberalization changes the relative price of resource-intensive goods. Changes in prices can fuel or diminish exploitation of the resource, and in the long run resource stocks may decline or increase. Most insights that are derived with respect to trade and renewable resources are based on analysis of a small open economy (Brander and Taylor, 1997). When resource prices are determined on world markets, prices are unresponsive to changes in the local harvest stock. Brander and Taylor (1997) show that if the country faces higher prices after trade liberalization then domestic exploitation will increase. In that case, unless the resource stock is managed optimally from an intertemporal perspective, chances are that any gains from trade are only temporary, since free entry of harvesters will dissipate all rents in the long run. Thus, trade can exacerbate the problem of open-access by encouraging excessive entry. Of course, trade liberalization might also benefit a small open economy if the initial resource price under autarky was higher than the world price. In that case, cheap imports from world markets allow resource stocks to recover from previous episodes of overexploitation under autarky.

It should be noted that many natural resources are not traded at all, e.g. ecosystem services and biodiversity, and therefore trade does not directly bear on the degradation of these resources. Still, natural resources such as biodiversity are dependent on the available stock of land, which is often the most important factor of production for natural resources. Land use for production, e.g. the use of land for agricultural activities, competes with the use of land for the preservation of natural resources. Even in this case, when natural resources are not directly traded on world markets, trade can have an impact on conservation. This is because trade can affect the opportunity cost of natural resource preservation. For example, higher world prices for agricultural goods following trade liberalization can increase the opportunity cost of resource preservation. New insights emerge when resource growth depends positively on habitat size. It can then be shown that higher resource prices lead to opposing effects on habitat conservation. On the one hand, higher resource prices increase exploitation thereby diminishing the resource stock. On the other hand, they make habitat conservation more profitable so that the resource base expands and resource growth increases. It is unclear which effect dominates in practice.

Since the welfare implications of trade in renewable resources are so dependent on what kind of regime is in place, much effort has been devoted to the analysis of institutions and management of renewable resources. In this context it has been argued that there exist important asymmetries at the global level, where the South appears to be at an obvious disadvantage with respect to the quality and enforcement of property rights. Chichilnisky (1994) is probably the first to emphasize that, due to inefficient institutions, the South is more likely to lose from trade than the North. If resources in the South are subject to open access then the competitive advantage of the South in world markets is only temporary and the resource abundance of the South is, at least to some extent, induced by the property rights regime. Recent research in this area stresses the role of enforcement of property rights and how changes in prices and resource stocks can trigger endogenous changes in property rights.

1.2 Thesis Overview

Chapter 2: On Biodiversity, Conservation Policy and Capital Mobility.

The second chapter in this thesis analyses the implications of economic integration, in the form of free capital mobility, for local and global biodiversity. Biodiversity depends positively on habitat size and competes with (agricultural) production for the use of land. Under economic integration, modelled as an exogenous reduction of capital market inefficiencies in South, capital flows from North to South. The analysis presented in this chapter is novel in the sense that most papers on trade and the environment have neglected the concept of capital mobility, which, next to international trade, forms another important facet of globalization (Bulte and Barbier, 2005). For many developing countries, the challenge of attracting capital and fostering economic activity within their borders runs counter to the need to protect biodiversity by conserving habitat area.

We employ a simple two-region general equilibrium model with three factors of production, one consumption good and where consumers derive amenity value from (global) biodiversity. We study both cases where countries cooperatively and non-cooperatively implement conservation (land) policies. Conservation policies represent a trade-off between consumption and species preservation for biodiversity purposes.

We find that non-cooperative conservation policies are subject to a so-called diversity induced substitution effect, which reduces land conservation, and which is distinct from the free-rider effect. The diversity induced substitution effect can be defined as the incentive to reduce local conservation efforts when foreign conservation efforts increase, and arises whenever there is some overlap between the different types of species across countries. For example, if South Africa's conservation areas increase in size then it might give Kenya an incentive to reduce the size of its conservation areas, since there is an overlap in wildlife between the two countries. We also find that second-best conservation policies and international investment might be used for purposes related to international income redistribution if international transfers are unavailable.

Chapter 3: The Pollution Haven Hypothesis: a Dynamic Perspective

In chapter 3 the focus shifts towards the pollution haven hypothesis. We adopt a dynamic perspective to this hypothesis by introducing capital accumulation in a two-country pollution haven model. This is an interesting approach since any analysis of trade and growth should incorporate the fact that many factors of production, i.e. capital, are actually produced inputs. Allowing countries to optimally accumulate capital, what are the implication for comparative advantage, factor prices, patterns of specialization and growth? (see Caliendo, 2010). A more specific question, closer to our topic of interest, is how (endogenous) cross-country differences in environmental policy affect the pattern of trade, growth and the evolution of local and global pollution.

Since a full-fledged dynamic analysis would take us to far ahead, the chapter focuses primarily on the question whether the pattern of trade in the long run is different from the pattern of trade as suggested by static models. We incorporate optimal saving and investment behavior into a $2 \times 2 \times 2$ Heckscher-Ohlin framework with environmental damage from pollution. In our model (i) both sectors of production make use of a polluting factor of production, (ii) pollution that is generated by production is local in nature and (iii) environmental policy is endogenous.

We derive necessary conditions, related to demand side and supply side parameters, under which a country can become a net exporter of the dirty good, i.e. a pollution haven. Our chapter adds to the literature by emphasizing the deeper determinants of specialization patterns and pollution havens, especially the subjective time discount rate.

Chapter 4: Does Corruption Discourage International Trade?

We concentrate on the effects of corruption on international trade in the fourth chapter. Our interest originates from the fact that the volume of trade is far less than predicted by theory, the so-called 'mystery of missing trade' (Trefler, 1995; Eaton and Kortum, 2002). This mystery has been connected to various types of trade frictions, natural and artificial, that still exist between countries. In this chapter we focus on corruption as a possible deterrent of bilateral trade. Contrary to previous empirical studies, we use measures of trade related corruption and compare the results with those of corruption in general. The variables used in our study more precisely reflect facts and experiences, and therefore are quite different from other corruption indicators, which rely on perceptions. Our main method of analysis is the gravity model, which has become the main modus operandi for empirical economists interested in trade related issues. Our cross-section analysis contains data on bilateral trade flows and corruption for both developing and developed countries, so that we can study the effect on international trade of i) the level of corruption, ii) the quality of institutions facilitating international trade, iii) the interaction between corruption and the quality of these institutions, and iv) the degree of unpredictability of corruption.

Our analysis reveals the importance of using variables directly related to corruption and institutions at the border. Often results are opposite to those found for corruption in general. Corruption in general hampers international trade, whereas bribe paying to customs enhances imports. This grease effect is most robust in importing countries with bad quality of customs. High waiting times at the border significantly reduce international trade. The effects of unpredictability of corruption and policies are inconclusive. The most robust results are found for waiting time at the border, a variable directly related to experience instead of perceptions. Furthermore, the effects for importing countries differ from those for exporting countries, so that distinguishing between the two is crucial.

Chapter 5: Can Globalization Outweigh Free-Riding?

In chapter 5 of this thesis we analyze the relationship between trade and the environment in a vertically integrated world economy, an international market structure that deserves further scrutiny given its empirical relevance. We build a model with a large number of countries that incorporates two key elements of a vertically integrated world economy: (i) each country specializes in a given set of intermediate goods (supply chain specialization) and (ii) each country requires the use of imports in order to produce exports (input-output structure). The production of intermediate goods generates (transboundary) pollution. Governments non-cooperatively decide on the strength of domestic environmental policy. This is an issue of concern, since we assume that governments are bound by international agreements and cannot use trade instruments.

Applying this model, we try to find answers to the following two questions. First, is it possible that decentralization, which refers to a world where the number of countries is large and trade intensity high, can lead to efficient environmental policies? Next to the traditional free-riding incentive we find that the stringency of environmental policy in each country is influenced by the incentive to raise the terms-of-trade and the incentive to internalize the negative impact of a lower supply of domestic intermediate goods on the foreign supply of intermediate goods. Decentralization is relevant since we find that the relative strength of these incentives is influenced by trade intensity, which is directly linked to the degree of decentralization. Second, what is the effect of globalization, as measured by the degree to which countries are connected via (inter)national input-output linkages, on the stringency of environmental policy, global pollution and welfare?

Our theory exhibits the possibility of negative carbon leakage: unilateral environmental policy decreases pollution at home and abroad. The reason is that stricter environmental policy in a number of countries will reduce the supply of intermediate goods to world markets. Since these commodities are used as inputs in the production of intermediate goods in other countries, a downward shift in supply will lower production in other countries as well. Furthermore, we find that a race-to-the-top is possible under non-cooperative policy making. Since countries do not internalize the negative effects on foreign welfare of higher prices induced by stricter environmental policies, non-cooperative policies might be too stringent compared to policies in the social optimum. A race to the top occurs whenever pollution is purely local. For problems related to transboundary pollution the situation looks grimmer: green welfare is likely to be higher in the social optimum. Nevertheless, both (i) stronger input-output linkages and/or (ii) international factor ownership can close the gap between the level of green welfare obtained in the non-cooperative solution and the social optimum. These aspects of globalization can partially outweigh the negative effect of free riding, which is strengthened under decentralization, on environmental quality.

Chapter 6: On Trade, Sustainable Development and Overlapping Kuznets Curves

In the last chapter of this thesis we again focus on the topic of trade, growth and the environment. We consider the idea of a global environmental Kuznets curve, i.e. the occurrence of an inverted u-shape relationship between *world* pollution and *world* income. We show how this curve, which arises on a transition path featuring a large number of heterogeneous countries, is actually composed of individual countries' Kuznets curves. We refer to this phenomenon as a pattern of 'overlapping Kuznets curves'. We augment the multi-country endogenous growth model of Acemoglu and Ventura (2002) by introducing smokestack pollution. To be specific, we assume smokestack pollution is generated as an unwanted by-product in the production process of intermediate goods industries. Our multi-country growth model is very tractable and offers valuable insights on global income-pollution trends. With pollution being transboundary in nature, overlapping Kuznets curves are actually a reflection of the timing and magnitude at which countries 'contribute' to preservation of the global commons. Thus, a Kuznets curve of a single country can be interpreted as its path of contributions. With differences in initial conditions, the transition path of our model is characterized by periods in which pollution is already decreasing in some countries while still increasing in others.

Our main contribution is to study the path and cross-country distribution of contributions to a global public good in a dynamic growth model. Our findings show that there is not likely to be a unique path of development for all countries. This could explain the difficulties in testing for the relationship between income and pollution in the context of global pollutants in cross-country studies. Second, with few exceptions, theories aimed at explaining the relationship between international trade and the environment are static in nature. Therefore, by employing a dynamic multi-country model that features trade in dirty intermediate goods we aim to be part of an ongoing endeavour to bridge the gap between the static literature on trade and the environment on the one hand and the dynamic literature on growth and the environment on the other hand.

Chapter 2

On Economic Integration, Biodiversity and Conservation Policy

2.1 Introduction

2.1.1 Globalization and Biodiversity Conservation

Since the beginning of the 1990s an increasing number of economists, biologists and other scientists have paid attention to questions concerning biodiversity conservation and the rate of species extinction. Although difficult to measure and forecast, current and predicted extinction rates seem far higher than historical rates. There is consensus that the root cause of this and other forms of environmental degradation is (economic) activity by humans. Environmental degradation manifests itself primarily in habitat loss, over-harvesting, invasive species and pollution of the environment (see Polasky et al., 2004; Eppink and van den Bergh, 2006). At the same time, economic growth in some parts of the world has been higher than ever before, and the world has seen a rapid increase in trade flows and international investments. Globalisation has taken a new pace at the same time when many ecosystems face growing pressure from human actions.

Heal finds that globalization, as defined by the increase in mobility of factors of production, the lowering of transport costs and the increase in international trade and investment, has not in itself lead to a decrease in biodiversity. He states that '*Population growth, habitat loss and biodiversity loss are global problems, in the sense that they are occurring globally and have global consequences. But they are not problems of globalization* (Heal, 2002)'.

The simple observation that habitat conversion and the resulting loss in biodiversity occur everywhere in the world is, according to Heal (2002), proof of this statement. Worldwide the scarcity of land has been greater than ever not just due to globalization, but because of fast growing populations and enormous boosts in income per capita. These developments imply that many species, and nature in general, compete with other (economic) activities for scarce resources. In fact, when valued at the margin many biological assets offer such a low rate of return that from an economic point of view disinvestment is not irrational at this point in time (Bulte and Van Kooten, 2000). Even restrictive trade policies can be ineffective at preserving biodiversity since policies that reduce the terms of trade might also increase the domestic opportunity cost of preserving habitat areas (Schulz, 1996; Barbier and Schulz, 1997).

Nonetheless, Heal's remarks can be criticized on several accounts. In sum we argue that globalization affects patterns of human economic activity with respect to space and time, and provides for many new opportunities that have no precedent in history. Let us elaborate more closely on these aspects of globalization. First, globalization may be a force of economic growth by itself. Empirically, there is some evidence that increased openness to trade and factor flows, given the right set of domestic institutions, increases the rate of economic growth. For example, many have argued that export-led growth was one of the main drivers behind the East-Asian growth miracle (Rodrik, 2003). So by providing for new opportunities of economic growth, reductions in tariffs, quota's, capital controls and other restrictions to trade and factor mobility have possibly fuelled a growth process that endangers global biodiversity. Theoretically, this would imply that the damaging scale effect from trade outweighs the preserving substitution and technology effects[1] from trade (Copeland and Taylor, 2003).[2]

Second, Heal's statement ignores the fact that reductions in transport costs have altered spatial patterns of economic activity. Both biodiversity and economic activity are not spread uniformly across space. For example, in the European Union there is often a larger discrepancy in income between different regions within a country than between various countries itself. Very much comparable to economics similar patterns of spatial heterogeneity exist in the biological realm. Some ecosystems such as tropical rainforests contain significantly more species than others. On a global scale, more than 80% of the world's biodiversity is contained in 5% of the world's land area. These areas are called ecological hotspots. Thus, spatial heterogeneity is an issue in both economics and ecology (Barbier and Rauscher, 2010; Eppink and Withagen, 2009) and the magnitude by which habitat conversion occurs is probably less relevant than the location where it takes place.

Third, globalization has affected the speed and scale by which mobile factors of production can relocate to other, more profitable regions. With less or no detachment to their original resource base, mobile factors have fewer incentives to acquire a sustainable relation with their environment. A careful investigation of this aspect seems to be absent in most of the work on trade, renewable resources and biodiversity (Barbier and Bulte, 2005).

2.1.2 Why Biodiversity and Factor Mobility?

There are many reasons for studying the relationship between factor mobility and biodiversity. First, most work in environmental economics has only focused on the connection between trade and biodiversity. From an empirical point of view this is understandable since international trade and the associated invasion of alien species are among the most important causes of species decline (Polasky et al., 2004).

[1]First, trade might lead to price increases of resource intensive or emission intensive commodities. Consumers respond to these price changes by substituting away from dirty goods towards cleaner goods. Second, trade might lead to the adoption of cleaner production technologies that ceteris paribus lower the level of pollution from production and consumption.

[2]The work by Copeland & Taylor (2003) mainly concerns the relation between environmental pollution and endowment driven trade patterns. Assuming biodiversity is also directly affected by pollution, their theoretical framework might apply here as well.

Nevertheless, other threats to the environment and biodiversity exist in the form of urbanization, industrialization and ecotourism. In particular, the underdevelopment theory of tourism describes the control of ecotourism resources by multinational enterprises in the developing world. For example, in Zimbabwe of the 1980s more than 90% of ecotourism revenues were expatriated to the parent countries. Only a small amount was reinvested in the home country causing excessive environmental degradation, among other problems related to sustainable development (Isaacs, 2000; Ziffer, 1989).

Second, from a theoretical perspective globalization is more than just international trade: factor mobility and foreign direct investment are also part of this phenomenon. In the related area of internationalization and environmental pollution theory has focussed on both models of trade and capital movements (Rauscher, 1997; Copeland and Taylor, 2003; Copeland and Taylor 1997). We conjecture that when examining environmental amenities theories that are based solely on trade models are no substitutes for models that include factor mobility (For models with trade only see Smulders et al. (2004) and Polasky et al. (2004)).

In the literature on tax competition it is readily understood that factor mobility matters for policy makers. With parts of the tax base becoming increasingly mobile, interjurisdictional competition in for example environmental regulations might lead to situations of a 'race to the bottom'. In addition, underprovision of public goods might occur since taxes on capital are too low in the Nash equilibrium when compared to the social optimum (Mieszkowski and Zodrow, 1986; Wilson, 1999). Biodiversity, like many environmental amenities, is an important example of a public good. The challenge of attracting capital and fostering economic activity within the borders of its jurisdiction runs opposite to another need, society's wish to protect biodiversity by habitat conservation. In these tax competition models, fiscal externalities and environmental externalities prevent individual states choosing policies that are optimal from a social point of view.

Most of the economics literature on biodiversity has focused on problems of economic policy in the context of goods mobility, i.e., models of trade and biodiversity. Polasky et al. (2004) and Smulders et al. (2004) consider the problem of habitat conversion, land-use and biodiversity in standard trade models. Polasky et al. (2004) show that, under the right conditions, trade liberalization leads to specialization of production across countries as well as specialization in terms of species. Smulders et al. (2004) find that, in contrast to Brander and Taylor (1997, 1998) and Jinji (2006), trade measures might be beneficial for the environment in the resource-rich country if the effect of reduced harvesting of natural resources outweighs the effect of habitat destruction that is the result of agricultural expansion.

Thus, there exist both theoretical and empirical reasons to study more closely the relation between factor mobility on the one hand, and biodiversity (conservation) on the other hand. Capital mobility is obviously an important ingredient in today's process of globalization. Therefore it is a potential source of habitat destruction and environmental degradation. To this end, this chapter studies the impact of capital mobility on (global) biodiversity in a simple two-region general equilibrium model with three factors of production, one consumption good and where consumers derive amenity value from (global) biodiversity. We study both cases where countries cooperatively and non-cooperatively implement conservation (land) policies. Conservation policies represent a trade-off between consumption and habitat preservation for biodiversity purposes. The choice for our model is warranted since on a conceptual level, a model of factor mobility, be it capital or labor, is the simplest model of economic integration. Since the global stock of capital is assumed to be constant, it allows us to isolate the integration effect from pure growth effects arising from factor accumulation. In that respect the model applied in this chapter is convenient, easy to use and adheres to the basic needs when thinking about the concept of economic integration.

The outline of the rest of the chapter is as follows. In section 2 we discuss the model. Section 3 starts off with an analysis of non-cooperative conservation policies in autarky. It also discusses comparative statics with respect to some critical parameters under endogenous land policy. Our analysis of biodiversity conservation and economic integration commences in section 4. We first analyze the determinants of foreign investment in a small open economy and also discuss implications for welfare. We then turn to an analysis of capital market integration in a two-country model and focus on some results related to comparative statics. Assumptions with respect to the functional form of the biodiversity index turn out to be important. In section 5 we contrast a (second-best) cooperative solution, where international transfers are unavailable, to the non-cooperative solution, where countries compete in land policies. Some implications for the stringency of conservation policy, income and economic integration are discussed in section 6. The last section concludes.

2.2 A Simple Neoclassical Framework

2.2.1 Factor Endowments and Factor Mobility

We consider a model of two (asymmetric) regions, North and South. Variables in the South are denoted by an asterix (*). Capitals denote variables, whereas small letters are used for functions. Both regions produce a homogeneous consumption good under constant returns to scale and perfect competition. We normalize the price P of the consumption good, $P = 1$. The good is produced using three factors of production: land T_M, labor L and capital K. The letter M is a mnemonic for manufacturing, although the aggregate good can be interpreted as some appropriate aggregation of various sectors. Our setting is similar to Rauscher (1997) and Wang (1995), who consider the relation between capital mobility and pollution.

labor and land are immobile factors of production. Capital is mobile across regions. Both regions are endowed with a fixed amount of land and labor, a stock T and L in the North and a stock T^* and L^* in the South. Capital owned (K_0) by Northern residents differs from capital employed (K) in the North. Capital owners are not mobile and capital earnings are repatriated to the country of origin. The total stock of capital in the North and South is fixed and either employed at home (K_M) or abroad (K_X), $K_0 = K_M + K_X$ and $K_0^* = K_M^* + K_X^*$. Defining net North-South investment I as $I = K_X - K_X^*$, we can classify capital employed as

$$K = K_0 - I \quad , \quad K^* = K_0^* + I \tag{2.1}$$

In our deterministic setting, where capital owners (re)locate capital in order to maximize their net return on capital, cross-hauling of capital does not occur and therefore the number of different net capital allocations is rather limited. Either North is a net capital investor, $K_X > 0$ and $K_X^* = 0$ such that $I > 0$, or the South is a net capital investor, $K_X = 0$ and $K_X^* > 0$ such that $I < 0$. In what follows we continue by making use of these definitions in (2.1) when referring to

the cross-country or global allocation of capital.

2.2.2 Ecology and Biodiversity

The ecological part of the model consists of a concave relation between the amount of land available for habitat purposes T_H and the number of local species s, known as the species-area curve:

$$s = s(T_H) \quad , \quad s_T \equiv \frac{ds}{dT_H} > 0 \, , \, s_{TT} \equiv \frac{d^2 s}{(dT_H)^2} < 0$$

At times we may use a special functional form for the species-area curve, which includes a parameter κ for ecosystem productivity:

$$s = \kappa T_H^{\varphi} \;\; , \;\; 0 \leq \varphi \leq 1 \tag{2.2}$$

We note that κ might differ across countries such that ecosystems in South might be more 'productive' in terms of the number of species they generate for a given endowment of land. These differences in κ might represent differences in climate, geography etc. The total endowment of land is fixed and is available for either production or habitat area: $T = T_H + T_M$. Of course, in reality species do not only survive within protected areas and there does not need to be a strict separation between economic activity and species preservation (See Polasky et al. (2008)). The species-area curve first appeared in the island-biogeography literature. This literature, initiated by ecologists MacArthur and Wilson (1967), tried to find explanations for the number of species in a particular community. The theory holds that through migration and extinction the equilibrium number of species in a particular community or island can be inferred from area size and distance from the mainland. Large islands are characterized by a larger biological diversity, as are islands close to the mainland and close to the equator.

We assume that the government owns the property rights of the whole land-area. The government can protect biodiversity in its region by setting a high, (uniform) tax on land, thereby limiting the conversion of habitat area in land that is used in production. As a result of this simple property rights regime, the demand for land T_M by firms is a function of the tax rate t_M, the capital stock K and population size L in a particular country. Alternatively, it can also set a quota on the use of land.

2.2.3 Production and Capital Market Frictions

Production in each country takes place under conditions of constant returns to scale and perfect competition, $Q = f(K_0 - I, L, T_M)$. The first and second-order derivatives have the usual signs with diminishing returns to one input and positive cross derivatives, $f_i > 0$, $f_{ii} < 0$, $f_{ij} > 0$ for all $i, j = K, L, T$.[3] We assume $\lim_{K_0^* + I \to 0} f_K^* = +\infty$, provided $L^* > 0$ and $T_M^* > 0$, and $\lim_{T_M^* \to 0} f_T^* = +\infty$, provided

[3] We define $f_T \equiv \frac{\partial f}{\partial T_M}$ and $f_{TT} \equiv \frac{\partial^2 f}{\partial T_M{}^2}$ to simplify notation.

$L^* > 0$ and $K_0^* + I > 0$. A similar set of Inada conditions holds for North. Producers take factor-prices as given. Government policy consists of either setting the tax rate t_M on land or determining the quota T_M. The profit function of a representative Northern (Southern) producer is then given by

$$\pi = Q - r(K_0 - I) - wL - t_M T_M \tag{2.3}$$

Under conditions of perfect competition (and no factor market distortions), all factors of production are paid their marginal product. With the exception of capital employed in the South and its owners, all factor owners also receive their marginal product. We assume, however, that the capital market in the South is characterized by frictions. These frictions imply that capital owners receive $\frac{r^*}{1+\rho}$ per unit of capital employed in the South, where $\rho \geq 0$ measures the strength of the capital market frictions. Frictions might arise, for example, due to transaction costs between firms and capital owners.

Profit maximization by producers leads to the following set of first-order conditions:

$$f_K = r \quad , \quad f_L = w \quad , \quad f_T = t_M \tag{2.4}$$

$$f_K^* = r^* \quad , \quad f_L^* = w^* \quad , \quad f_T^* = t_M^* \tag{2.5}$$

Capital owners in North and South (re)locate capital in order to maximize their net return on capital, which will equalize the return on capital across North and South, $r = \frac{r^*}{1+\rho}$. Using (2.4)-(2.5) this arbitrage condition becomes:

$$f_K(1 + \rho) = f_K^* \tag{2.6}$$

Using the four factor market conditions for land and labor from (2.4)-(2.5) and equation (2.6), we have a system of five equations with four exogenous variables (L, L^*, t_M, t_M^*) which can be used to solve for the set of five endogenous variables (K, w, w^*, T_M, T_M^*).[4] Note here that the total stock of world capital is fixed ($K^w = K + K^*$) such that we only have to solve for K. Under a system of land quotas the factor market conditions for land, $f_T = t_M$ and $f_T^* = t_M^*$, are redundant and we are left with a system of 3 equations in 3 unknowns (K, w, w^*).

Finally, in what follows we will differentiate between the case of a small open economy and a two-country world economy. In a small open economy the interest rate r is taken as given and equal to the world interest rate ($r = r^w$) whereas in the two-country case r is endogenous and determined by tax and land policies in both countries, among other factors. These conditions boil down to respectively $\frac{f_K^*(K^*+I,L^*,T_M^*)}{1+\rho} = r^w$ for the small open economy, and the arbitrage condition $r = f_K(K - I, L, T_M) = \frac{f_K(K^*+I,L^*,T_M^*)}{1+\rho} = \frac{r^*}{1+\rho}$ for the two-country model. These two assumptions make a big difference for policymaking and biodiversity conservation, since it is through the interest rate that land policy has a big impact on lending, conservation and welfare.

[4] From $(f_K - t_K)(1 + \rho) = f_K^* - t_K^*$ one can solve for $I = I(T_M, T_M^*)$. Substitution into $f_T = t_M$ then gives us $T_M = T_M(T_M^*)$ and subsequently $I = I(T_M(T_M^*), T_M^*) = I(T_M^*)$. Substitution of $I(T_M^*)$ into $f_T^* = t_M^*$ then solves for T_M^* as a function of exogenous variables. All other variables follow.

2.2.4 Welfare and Consumption

We normalize population size in the North (South) to one and abstract from factor distribution issues. Land taxes are redistributed to consumers in a lump-sum fashion. Utility of the representative consumer is linearly additive in private consumption C and biodiversity B:

$$V(C, B) = u(C) + \eta B \quad , \quad \eta > 0 \, , \tag{2.7}$$

where η measures the constant marginal benefit from biodiversity[5]. In the absence of savings consumption equals national income, $C = wL + r(K_0 - I) + \frac{r^*}{1+\rho} I + \pi + t_M T_M = Q + r^* I - \frac{\rho}{1+\rho} r^* I$ and similarly for the South where $C^* = w^* L^* + \frac{r^*}{1+\rho} K_0^* + \pi^* + t_M^* T_M^* = Q^* - r^* I - \frac{\rho}{1+\rho} r^* K_0^*$.[6] Consumption C (C^*) thus equals the net national product Q ($Q^* - \frac{\rho}{1+\rho} r^* K_0^*$) plus imports (minus exports) that equal the net return on (net payments to) foreign investment. In the absence of capital market frictions we obtain $C = Q + r^* I$ and $C^* = Q - r^* I$.

Returning to the ecological side of the mode, habitat loss ($dT_M = -dT_H$) negatively affects species numbers at home and the biodiversity index B is increasing in local and foreign species numbers:

$$B = b(s, s^*) = b(s(T_H), as^*(T_H^*)) \quad , \quad T = T_H + T_M \tag{2.8}$$

$$B^* = b^*(s, s^*) = b(As(T_H), s^*(T_H^*)) \quad , \quad a, A > 0 \tag{2.9}$$

$$b_T \equiv \frac{db}{dT_M} = -b_s s_T < 0 \quad , \; b_{T^*} \equiv \frac{db}{dT_M^*} = -a b_{s^*} s_{T^*} < 0$$

where $b_s \equiv \frac{\partial b}{\partial s} > 0$, $b_{ss} \equiv \frac{\partial^2 b}{\partial s^2} \leq 0$, $b_{s^*} \equiv \frac{\partial b}{\partial s^*} > 0$, $b_{s^*s^*} \equiv \frac{\partial^2 b}{(\partial s^*)^2} \leq 0$ and $b_{ss^*} = b_{s^*s} \geq 0$. A decrease in land available for habitat purposes means a decrease in local species numbers, thereby lowering the biodiversity index at home and abroad. These definitions of biodiversity also include the possibility of different valuation of foreign species and local species (a, $A > 0$). The specification of species numbers and biodiversity in (2.2) and (2.8)-(2.9) implies that we consider geographically separated countries.

Although so far we have refrained from using specific functional forms, we will often do so in the remainder of this chapter. We will ocassionally refer to the following set of functional forms as our leading example:

Leading Example. *Assume* $b(s, s^*) = s + as^*$, $b^*(s, s^*) = As + s^*$, $Q = \psi L^\alpha (K_0 - I)^\beta (T_M)^\chi$, $Q^* = \psi (L^*)^\alpha (K_0^* + I)^\beta (T_M^*)^\chi$, $V = \log C + \eta(s + as^*)$, $V^* = \log C^* + \eta^*(As + s^*)$, $s = \kappa(T_H)^\varphi$ *and* $s = \kappa^*(T_H^*)^\varphi$ *with* $\alpha + \beta + \varkappa = 1$.

[5] An alternative interpretation of (2.7) states that consumers care about unused land (see (2.2)). In reality there might be many environmental amenities next to biodiversity that can be derived from unused land.

[6] The expressions for consumption, $C = Q + r^* I - \frac{\rho}{1+\rho} r^* I$ and $C^* = Q^* - r^* I - \frac{\rho}{1+\rho} r^* K_0^*$, clearly show that $\frac{\rho}{1+\rho} r^* K_0^*$ and $\frac{\rho}{1+\rho} r^* I$ represent the total consumption loss for the South and North respectively due to capital market frictions in South. The global loss equals $\frac{\rho}{1+\rho} r^* (K_0^* + I)$.

2.3 Autarky

In autarky there is no trade in capital and goods ($I = 0$). As a result, both countries can produce only with available domestic factors of production. In the absence of international capital markets this also implies that r and r^* are determined domestically. We also abstract from capital market frictions in the South ($\rho = 0$). Consumption equals the national product, $C = Q = f(K_0, L, T_M)$ and $C^* = Q^* = f(K_0^*, L^*, T_M^*)$. Land policy by the government determines the amount of land T_M that is available for production. The government maximizes utility (2.7) subject to the budget constraint, and a land endowment restriction (2.8):

$$\max_{\{T_M\}} V = u(Q) + \eta b(s, s^*) \tag{2.10}$$

leading to the following first-order condition for the North:

$$u_C f_T - \eta b_s s_T = 0 \tag{2.11}$$

where the first term on the left-hand side represents the marginal benefit from using an additional unit of land in production and the right-hand side represents the marginal cost of using an additional unit of land for production. A similar first-order condition holds for the South. The optimal price (tax) of land $\hat{t_M}$ equates marginal benefits and marginal costs:

$$\hat{t_M} = f_T = \frac{\eta b_s s_T}{u_C} > 0 \tag{2.12}$$

Alternatively, the government can decide to implement a quota T_M such that (2.11) holds with strict equality and the resulting market price for land equals the marginal productivity of land f_T. Since the optimal price of land in (2.12) is equated to local, not social, marginal cost of habitat loss a sub-optimal equilibrium arises with quotas (taxes) that are too generous (too low).

Even in autarky land policy is not determined by domestic considerations alone because biodiversity is considered a global public good. Non-cooperative land policy balances the benefits from habitat protection and utility derived from consumption, given the quota or tax set in the other country. Inspecting (2.12) shows that the tax (or quota) set in the other country influences domestic policy through the term $b_s(s(T_M), as^*(T_M^*))$. If North does not value Southern species ($b = s$) or when ecosystems are characterized by full species endemism ($b(s, s^*) = s + s^*$) then the choice of the optimal quota is independent of the policy in the other country. Note that with endemic species we refer to species that are unique to a certain ecosystem and/or geographic location.

Although in general a closed-form solution for the non-cooperative tax is not available, it is possible to derive the 'reaction curves' of the North (or South) in autarky by totally differentiating the conditions for optimal land policy with respect to T_M and T_M^*:

$$\frac{dT_M}{dT_M^*} = \frac{-A\eta b_{ss*} s_T^* s_T}{u_{CC}(f_T)^2 + u_C f_{TT} + \eta b_{ss}(s_T)^2 + \eta b_s s_{TT}} < 0$$

These derivatives show us that land policies in North and South are strategic substitutes in autarky. A marginal reduction (increase) of habitat area in the South will lead to a marginal increase (reduction) of habitat area in the North and vice versa.

In terms of public goods characteristics it is interesting to contrast biodiversity with (the reduction of) carbon emissions. Feedbacks in autarky through non-cooperative policies usually only arise with damage functions that are strictly convex (see Copeland and Taylor (2005)). Here we find that even in autarky with no trade in capital and a linear benefit function, countries have an incentive to 'undercut' the other country by relaxing its land policy. The reason is, of course, that biodiversity conservation does not necessarily represent the same type of public good as climate change. Unlike the benefits from reductions in carbon emissions, biodiversity conservation benefits depend strongly on where they take place: habitat conservation efforts in the European Union or the Amazon rain forest in Brasil are likely to differ in terms of the type of species they preserve.

One of the questions that arises next is whether capital market integration will increase or diminish the problems that are associated with providing for an optimal amount of this public good. Obviously, strategic interaction may quite well lead to under provision of biodiversity even in the absence of trade.

2.3.1 Autarky Comparative Statics

The optimal autarky tax rate on land relates the benefits of more land usage in the form of higher consumption against the damage to biodiversity. Thus there is an obvious trade-off between consumption and biodiversity conservation. We now consider how changes in some important model parameters affect land policy. To determine how: (i) the marginal valuation of biodiversity η^*, and (ii) ecological productivity κ (κ^*) affect the optimal land policy (tax or quota), we totally differentiate the first-order condition (2.11) for optimal land policy of the South and equation (2.2) with respect to T_M, T_M^*, κ, κ^* and η^*. Most results obtained are straightforward. A marginal increase in the marginal valuation of biodiversity η^* increases the incentive to implement a strict land policy, $\frac{dT_M^*}{d\eta^*} < 0$. A marginal change in foreign ecosystem productivity κ on the other hand decreases conservation efforts, $\frac{dT_M^*}{d\kappa} \geq 0$. Somewhat more complicated is the effect of a marginal change in a country's own ecosystem productivity on its conservation policy:

$$\frac{dT_M^*}{d\kappa^*} = \frac{\eta^*(b_{s*}s_{T\kappa}^* + b_{s*s*}(s_T^*)^2)}{u_{CC}^*(f_T^*)^2 + u_C^* f_{TT}^* + \eta^* b_{s*s*}(s_T^*)^2 + \eta^* b_{s^*} s_{TT}^*} \tag{2.13}$$

There are two conflicting forces. First, there is a 'positive' effect from increased ecosystem productivity on the stock of land used in production. Since the biodiversity index is assumed to be concave, $b_{s*s*} \leq 0$, the positive effects of increases in carrying capacity eventually 'die out'. Thus, there comes a point where greater environmental capacity needs to be 'traded' for more productive land use (income effect). Second, there is a negative effect. A higher carrying capacity increases the returns from 'existing' habitat area ($s_{T\kappa}^* > 0$). This induces the country to increase the stock of land devoted to habitat (substitution effect). The sign of (2.13) depends on the relative strength of the income effect and the substitution effect.

Two remarks are in order with respect to the derivation of (2.13). First of all, it is probably more realistic to consider changes in ecosystem productivity that are correlated across different regions. Therefore we consider a global shock, for example as the result of climate change, that causes an (asymmetric) reduction in worldwide ecosystem productivity, $d\kappa = \tau d\kappa^* < 0$ with $\tau > 0$. Second, one would expect both countries to change their land policy in the face of climate change. The optimal changes in land use can then be given by totally differentiating both first-order conditions for optimal land policy:

$$\frac{dT_M^*}{d\kappa^*} = \frac{\eta^*(b_{s*}s_{T\kappa}^* + b_{s*s*}s_T^*s_\kappa^* + \tau b_{s*s}s_T^*s_\kappa) - \eta^* b_{s^*s}s_T^*s_T\tau\frac{dT_M}{d\kappa}}{u_{CC}^*(f_T^*)^2 + u_C^*f_{TT}^* + \eta^* b_{s*s*}(s_T^*)^2 + \eta^* b_{s^*}s_{TT}^*} \tag{2.14}$$

$$\frac{dT_M}{d\kappa} = \frac{\eta(b_s s_{T\kappa} + b_{ss}s_T s_\kappa + b_{ss*}s_T s_\kappa^*/\tau) - \eta b_{ss^*}s_T s_T^*\frac{1}{\tau}\frac{dT_M^*}{d\kappa^*}}{u_{CC}(f_T)^2 + u_C f_{TT} + \eta b_{ss}(s_T)^2 + \eta b s_{TT}} \tag{2.15}$$

The derivatives (2.14)-(2.15) show that, besides the standard income and substitution effects, there now is an extra term that makes the overall effect more likely to be positive. This implies that compared to a shock that only affects local ecosystems, a global shock is more likely to increase global land conservation.

2.4 Capital Market Integration

2.4.1 Foreign Investment in the Small Open Economy

Next, we turn to the determination of optimal biodiversity conservation under endogenous investment in South. We adopt the small open economy assumption. The Inada conditions, as set in section 2.3, guarantee that we can always construct an interior equilibrium with positive investment and biodiversity conservation by choosing K_0^* sufficiently small. As explained in section 2.3, the capital market condition for the small open economy reads $f_K^*(K_0^* + I, L^*, T_M^*) = (1+\rho)r^w$. The problem for the small open economy is identical to that under autarky (see 2.10), except that now consumption C^* equals $\left(Q^* - \frac{\rho}{1+\rho}r^*K_0^*\right) - r^*I = Q^* - \rho r^w(K_0^* + I) - r^w I$. We also abstract from the use of land policy to attract foreign investment; policy makers thus take I as given when determining the optimal land policy and implement a Pigouvian tax ($t_M = \hat{t}_M$). Such a situation might arise if policy makers are binded by restrictions as set out in a bilateral or multilateral investment agreement. In section 5 we discuss cases where policy makers do not take I as given.

Under these assumptions, the optimal land policy for the small open economy reads $u_C^*f_T^* - \eta^* b_{s^*}^* s_T^* = 0$. Investment I and land use T_M^* are then simultanously determined by the following set of two equations:

$$f_K^*(K_0^* + I, L^*, T_M^*) = (1+\rho)r^w \tag{2.16}$$

$$u_C(Q^* - \rho r^w(K_0^* + I) - r^w I)f_T(K_0^* + I, L^*, T_M^*) = \eta b_s(s, s^*(T^* - T_M^*))s_T^*(T^* - T_M^*) \tag{2.17}$$

where total differentiation of (2.16) gives us $I = I(\underset{+}{L^*}, \underset{+}{T_M^*}, \underset{-}{(1+\rho)r^w}) - K_0^*$ and total differentiation of (2.17) gives us $T_M^* = T_M^*(\underset{+}{I}, \underset{\pm}{K_0^*}, \underset{\pm}{L^*}, \underset{+}{r^w}, \underset{-}{s}, \underset{\pm}{T^*}, \underset{-}{\eta^*}, \rho)$, where the various subscripts indicate the sign of the partial derivatives. Here, a $\pm$ means the sign of the partial derivative is ambiguous. Again, the government can implement a quotum such that (2.17) holds, or set the tax on land t_M^* equal to $\frac{\eta^* b_{s*}^* s_T^*}{u_C^*}$.

Applying the functional forms from our leading example, we obtain from (2.16) that $K_0^* + I = (\frac{\psi\beta}{(1+\rho)r^w})^{\frac{1}{1-\beta}}(L^*)^{\frac{\alpha}{1-\beta}}(T_M^*)^{\frac{\chi}{1-\beta}}$. Using this result in (2.17) then gives us:

$$\chi R(T_M^*)^{\frac{-\alpha}{1-\beta}} = \varphi\eta^*\kappa(T^* - T_M^*)^{\varphi-1}[(1-\beta)R(T_M^*)^{\frac{\chi}{1-\beta}} + r^w K_0^*] \tag{2.18}$$

where $R \equiv (\frac{\psi\beta}{(1+\rho)r^w})^{\frac{\beta}{1-\beta}}(L^*)^{\frac{\alpha}{1-\beta}} > 0$. Where the left-hand side of (2.18) is strictly decreasing in T_M^* the right-hand side is strictly increasing in T_M^*. In addition, the left-hand side goes to infinity when T_M^* goes to zero whereas the right-hand side attains a strictly positive value, that is, $\varphi\eta^*\kappa(T^*)^{\varphi-1}r^w K_0^* > 0$. Thus, equation (2.18) has an unique solution to T_M^*.

Next, we turn to an analysis of the welfare implications from the inflow of foreign investment in a small open economy.

2.4.2 Welfare Effects from Foreign Investment

In this section we study the impact of a marginal increase in foreign investment on welfare and analyze the conditions under which welfare increases. From (2.16) we observe that capital market frictions in the South ($\rho > 0$) prevent equalization of the domestic interest rate and the world interest rate, $r^* > r^w$. Now suppose there is an exogenous decline in the capital market frictions, $d\rho < 0$. We can show that this will bring about a marginal increase in foreign investment. We differentiate (2.16) with respect to I, T_M^* and ρ, and rearrange to get $\frac{dI}{d\rho} = \left(1 + \frac{f_{KT}^*}{f_{KK}^*}\frac{dT_M^*}{dI}\right)^{-1}\frac{r^w}{f_{KK}^*}$. If there is a quota on land use, and T_M^* is fixed, we obtain $\frac{dI}{d\rho} = \frac{r^w}{f_{KK}^*}$. Under a land tax regime we differentiate the land market condition (see (2.5)) with respect to I and T_M^*, and (2.4) with respect to I and T_M, and rearrange terms to obtain

$$\frac{dT_M^*}{dI} = -\frac{f_{TK}^*}{f_{TT}^*} > 0 \quad , \quad \frac{dT_M}{dI} = \frac{f_{TK}}{f_{TT}} < 0 \tag{2.19}$$

Substitution then leads to $\frac{dI}{d\rho} = \left(\frac{f_{TT}^*}{f_{KK}^* f_{TT}^* - f_{TK}^* f_{KT}^*}\right) r^w < 0$. Thus, under both forms of land policy a marginal decrease in ρ results in a marginal inflow of foreign capital.

Next, we evaluate how a marginal inflow of foreign capital, caused by an exogenous decline in ρ, affects welfare by differentiating (2.7), subject to (2.8) and $C^* = (Q^* - \rho r^w(K_0^* + I)) - r^w I$, with respect to ρ to obtain the following derivative:

$$\begin{aligned} \frac{dV^*}{d\rho} &= -u_C^* r^w(K_0^* + I) + u_C^*\left(f_K^* - f_K^* + f_T^*\frac{dT_M^*}{dI}\right)\frac{dI}{d\rho} \\ &\quad -\eta^*\left(Ab_s s_T\frac{dT_M}{dI} + b_{s*}s_T^*\frac{dT_M^*}{dI}\right)\frac{dI}{d\rho} \end{aligned} \tag{2.20}$$

To analyze (2.20) in more detail, let us consider the effects under (i) an (optimal) land quota and (ii) an (optimal) land tax. What happens if the government imposes a quota? Welfare may decline if habitat area is excessively converted into productive land area, causing extinction of a large number of local species. If a strict policy, that is, an enforceable quota ($dT_M^* = dT_M = 0$) is in place in both countries the welfare effects are:

$$\frac{dV^*}{d\rho} = -u_C^* r^w (K_0^* + I) < 0$$

Welfare always increases due to the efficiency gain from the reduction in capital market frictions.

Let us now consider the welfare effects under a land tax. In this case the inflow of capital increases the productivity of land, which in turn increases the demand for land. As a consequence, habitat area is converted into land area for production (agriculture, manufacturing etc.). For the conversion of habitat area due to an increase of investment, $\frac{dT_M^*}{dI}$, we refer to (2.19). Substitution of (2.19) into (2.20) leads to:

$$\begin{aligned} \frac{dV^*}{d\rho} &= -u_C^* r^w (K_0^* + I) - u_C^* f_T^* \frac{f_{TK}^*}{f_{TT}^*} \frac{dI}{d\rho} \\ &\quad -\eta^* \left(A b_s s_T \frac{f_{TK}}{f_{TT}} - b_{s*} s_T^* \frac{f_{TK}^*}{f_{TT}^*} \right) \frac{dI}{d\rho} \end{aligned} \tag{2.21}$$

The effects of investment on welfare are ambiguous. First, there is the efficiency gain in the South due to a decrease in ρ. Second, a marginal increase in investment raises capital productivity in South, increases the demand for land and as a result the use of land in production increases. Both effects lead to an increase in consumption that positively affects welfare in South. The sign of the third term is ambiguous and represents the global change in biodiversity. On the one hand, in North more land will come available for habitat purposes ($\frac{dT_M}{dI} < 0$) due to an outflow of capital. On the other hand, production is intensified in the South and local species are under pressure due to loss of habitat. The overall effect on welfare from a marginal increase in investment is not clear.

Result 1. *(i) Under a tax-on-land regime a reduction of capital market frictions leads to an inflow of capital, increases land as a factor of production, increases consumption and decreases (increases) local (foreign) biodiversity. If the marginal productivity of land f_T^* is relatively small and/or foreign biodiversity is not highly valued (small A) and/or the foreign species-area curve is very concave (s_T small), then welfare in South declines. (ii) Welfare in South necessarily increases with an optimal land policy in place ($t_M^* = \frac{\eta^* b_{s*} s_T^*}{u_C^*}$).*

From (2.21) we find that a necessary condition for welfare to decline due to a decrease of ρ, $\frac{dV^*}{d\rho} > 0$, is $\left| -u_C^* r^w (K_0^* + I) - u_C^* f_T^* \frac{f_{TK}^*}{f_{TT}^*} \frac{dI}{d\rho} - \eta^* A b_s s_T \frac{f_{TK}}{f_{TT}} \frac{dI}{d\rho} \right| < \left| -\eta^* b_{s*} s_T^* \frac{f_{TK}^*}{f_{TT}^*} \frac{dI}{d\rho} \right|$. Note that with an optimal tax in place, $t_M^* = f_T^* = \frac{\eta^* b_{s*} s_T^*}{u_C^*}$, welfare always increases now that the price of land is set in such a way that at the margin an optimal trade-off between consumption and habitat loss is assured. In the absence of an optimal land policy there is no guarantee that trade in capital will increase welfare of the capital-poor region.

2.4.3 Comparative Statics of Capital Market Integration

In the previous section we were concerned with the welfare effects of a marginal reduction in capital market frictions. We now extend this analysis to a general equilibrium setting. As explained in section 2.3, in a two-country world economy free mobility of capital ensures equalization of the (net) return on capital:

$$r^* = f_K^*(K^* + I, L^*, T_M^*) = (1+\rho) f_K(K - I, L, T_M) = (1+\rho) r \tag{2.22}$$

We envisage two different experiments: (i) an exogenous increase in North-South investment ($dI > 0$) and (ii) an exogenous decline in capital market frictions, $d\rho < 0$, which spurs a movement of capital from North to South ($dI > 0$).

- Exogenous increase in North-South investment ($dI > 0$).

Countries maximize welfare (2.7) by setting the optimal tax (or quota) on land use, thereby taking the policy in the other country as given. We furthermore assume that policy makers take the domestic interest rate and the international allocation of capital as given. This assumption ensures that policy makers do not use environmental policy to influence investment or to influence the total rents (payments) on foreign investment.[7] The first-order conditions for optimal land policy in North and South are:

$$\frac{dV}{dT_M} = u_C f_T - \eta b_s s_T = 0 \quad , \quad \frac{dV^*}{dT_M^*} = u_C^* f_T^* - \eta^* b_{s^*}^* s_{T^*}^* = 0 \tag{2.23}$$

We totally differentiate these first-order conditions for optimal land-policy with respect to T_M, T_M^* and I to obtain the following 'reaction' functions for the North and South:

$$\frac{dT_M}{dI} = \frac{u_{CC} f_T \frac{f_{KK}^*}{1+\rho} I + u_C f_{TK} - \eta b_{ss*} s_T s_T^* \frac{dT_M^*}{dI}}{u_{CC}(f_T)^2 + u_C f_{TT} + \eta (b_{ss}(s_T)^2 + b_s s_{TT})} \tag{2.24}$$

$$\frac{dT_M^*}{dI} = \frac{u_{CC} f_T^* f_{KK}^* (\frac{\rho}{1+\rho} K_0^* + I) - u_C^* f_{TK}^* - \eta^* b_{s*s} s_T s_T^* \frac{dT_M}{dI}}{u_{CC}^* f_T^* (f_T^* - f_{KT}^* \left(\frac{\rho}{1+\rho} K_0^* + I\right)) + u_C^* f_{TT}^* + \eta^* (b_{s*s*}(s_T^*)^2 + b_{s^*} s_{TT}^*)} \tag{2.25}$$

Define $X \equiv u_{CC}(f_T)^2 + u_C f_{TT} + \eta(b_{ss}(s_T)^2 + b_s s_{TT}) < 0$ and $X^* \equiv u_{CC}^* f_T^* (f_T^* - f_{KT}^* \left(\frac{\rho}{1+\rho} K_0^* + I\right)) + u_C^* f_{TT}^* + \eta^* (b_{s*s*}(s_T^*)^2 + b_{s^*} s_{TT}^*) \gtreqless 0$, but very likely negative provided ρ and I are sufficiently close to zero. Equation (2.25) states that land use in South changes due to four different effects; (i) an inflow of foreign capital increases the marginal productivity of natural resources ($-\frac{u_C^* f_{TK}^*}{X^*} > 0$ iff $X^* < 0$), (ii) an expansion of land use increases the outflow of payments to foreign capital ($\frac{u_{CC} f_T^* f_{KK}^* I}{X^*} < 0$ iff $X^* < 0$), (iii) an expansion of land use increases existing inefficiencies in the capital market ($\frac{u_{CC} f_T^* f_{KK}^* \frac{\rho}{1+\rho} K_0^*}{X^*} < 0$ iff $X^* < 0$) and (iv) an inflow of foreign capital changes land use in North thereby affecting global biodiversty ($-\frac{\eta b_{s*s} s_T s_T^*}{X^*} \frac{dT_M}{dI} \geq 0$ iff $X^* < 0$ and $\frac{dT_M}{dI} < 0$). We denote these four effects respectively as a complementary investment effect, a rent-shifting effect, an institutional inefficiency effect and a

[7] Moreover, in case they would actually internalize these effects, comparative statics with respect to capital market frictions would include 3th-order derivatives. In such a case it would also be very difficult to interpret our findings.

diversity-induced substitution effect. In South the complementary investment effect raises the input of land in production whereas the institutional inefficiency effect and the rent-shifting effect lower the input of land. The variety-induced substitution effect raises the input of land in production in South provided $\frac{dT_M}{dI} < 0$. Note that the institutional inefficiency effect is not present in North.

The diversity-induced substitution effect states that South, in response to an expansion of habitat area and species numbers in North, should decrease local habitat area. An increase of species numbers abroad works as a windfall in terms of welfare: it is optimal for South to "convert" a part of the welfare increase to consumption by decreasing local habitat area.

Simplifying notation such that $\frac{dT_M}{dI} = (Z - D\frac{dT_M^*}{dI})/X$ and $\frac{dT_M^*}{dI} = (Z^* - D^*\frac{dT_M}{dI})/X^*$, we can obtain the 'general equilibrium' effects of a marginal change in investment on land policy by substitution:

$$\frac{dT_M}{dI} = \frac{ZX^* - Z^*D}{XX^* - DD^*} \tag{2.26}$$

$$\frac{dT_M^*}{dI} = \frac{Z^*X - ZD^*}{XX^* - DD^*} \tag{2.27}$$

since $X < 0$, $X^* \gtrless 0$ but very likely negative provided ρ and I are sufficiently close to zero, $Z \equiv u_{CC} f_T \frac{f_{KK}^*}{1+\rho} I + u_C f_{TK} > 0$, $D \equiv \eta b_{s*s} s_T s_T^* \leq 0$, $D^* \equiv \eta^* b_{s*s} s_T s_T^* \leq 0$ and $Z^* \equiv u_{CC} f_T^* f_{KK}^* (\frac{\rho}{1+\rho} K_0^* + I) - u_C^* f_{TK}^* \gtrless 0$, but very likely negative provided ρ and I are sufficiently close to zero, we find that both derivatives are ambiguous. Note that D and D^* are crucial for the strength of the diversity-induced substitution effect in North and South, respectively. Thus, equations (2.26)-(2.27) make it difficult to come up with general statements regarding the change in local and global biodiversity following a marginal increase in capital market integration.

- Endogenous increase in North-South investment (via $d\rho > 0$).

How do our results change under endogenous investment? In the appendix we show that the derivatives in (2.24)-(2.25) are amended by various novel effects. First, a decrease in capital market frictions implies a direct efficiency gain for South. Since biodiversity conservation is a normal good, this tends to increase habitat conservation through an income effect. Second, we have to account for general equilibrium interactions between the international capital market and the resource markets. These general equilibrium considerations introduce an additional interaction between resource conservation in North and South next to the diversity-induced substitution effect. Since investment is now endogenous, we find that the complementary investment effect and the rent-shifting effect in North and South are now interdependent. Whereas the complementary investment effects tends to increase land use in South after a decrease of land use in North (strategic substitutes), the rent-shifting effect tends to diminish land use in South as well (strategic complements). The relative strength of the rent-shifting effect, the complementary investment effect and the diversity-induced substitution effect will determine whether land policies in North and South are strategic substitutes or strategic complements. Thus, in sharp contrast to a situation with exogenous investment, under institutional progress ($d\rho < 0$) the interaction of countries via international capital markets might trigger increases in global public good provision by both countries, i.e. when policies are strategic complements.

2.4.4 Strategic Interaction, the Biodiversity Index and Diversity-Induced Substitution

The previous section explained how D and D^* are crucial for the strength of the diversity-induced substitution effect. In turn, the sign and value of D and D^* depend on b_{s*s} and b_{ss*} respectively, the cross partial derivative of the global biodiversity index. This derivative represents the effect from a marginal increase in Northern species numbers on the marginal increase in biodiversity from Southern species numbers, and vice versa. We consider two extremes (See Polasky et al. (2004) and Barbier and Rauscher (2007)):

•High Species Endemism, $B = b(s, s^*) = s + s^*$

Ecosystems in the North and South may be completely different and give home to a vast amount of species that are all country specific. Under this condition we observe that habitat destruction, which is the result of capital-led growth in industrial or agricultural activity, may lead to the extinction of a number of species that are unique to the booming region and for which no 'substitute' exists in other regions. High endemism lowers the likelihood that an increase in local species numbers makes an additional specie in the other region redundant. In this case the cross partial derivative is negative but small in terms of absolute value. For the extreme case of absolute species endemism, $b(s, s^*) = s + s^*$, the cross partial derivatives are zero, $b_{s^*s} = b_{ss^*} = 0$. Other derivatives of interest in this case are $b_{s*s*} = 0$ and $b_{s^*} = b_s = 1$ (see (2.23) and (2.24)-(2.25)).

•High Redundancy, $B = b(s, s^*) = \max\{s, s^*\}$

At the other side of the spectrum we may find a situation of high redundancy. Now both regions have very similar ecosystems and contain a set of local species that is found in the other region as well. Taken to the extreme, global biodiversity is just the maximum of species numbers' living in one of the two regions. Habitat destruction in one region does not automatically lead to global extinction of associated species. Here we find that the cross partial derivative is negative and large in absolute value. Under extreme high redundancy ($b(s, s^*) = \max\{s, s^*\}$) an increase in local habitat area and species numbers most "probably" makes an additional specie in the other region obsolete, $b_{s^*s} = b_{ss^*} = 0$. With respect to other derivatives of interest we have $b_{s^*} = 1$ and $b_s = 0$ for all $s^* \geq s$, and $b_{s^*} = 0$ and $b_s = 1$ for all $s^* < s$. Furthermore, this step-function implies that $b_{s*s*} = b_{ss} = 0$, except in the neighbourhood of $s = s^*$.

Let us consider the following example that allow us to make some specific statements regarding equations (2.26)-(2.27). We thus consider the case of an exogenous increase in North-South investment ($dI > 0$). Suppose initial endowments and ecosystem productivities (κ and κ^*) are such that $I = 0$ and $s^* > s$. Furthermore, we assume $\rho = 0$.

Example. Endemic Species: *Assume* $b(s, s^*) = s + s^*$ *and* $b^*(s, s^*) = s + s^*$. *Subsequently we have* $D = D^* = 0$, $Z > 0$, $Z^* < 0$. *We then find that* $\frac{dT_M}{dI} = \frac{Z}{X} = \frac{u_C f_{TK}}{u_{CC}(f_T)^2 + u_C f_{TT} + \eta s_{TT}} < 0$ *and* $\frac{dT^*_M}{dI} = \frac{Z^*}{X^*} = -\frac{u^*_C f^*_{TK}}{u^*_{CC}(f^*_T)^2 + u^*_C f^*_{TT} + \eta^* s^*_{TT}} > 0$.

This example points out that some clear-cut results can be obtained when one is willing to assume extreme types of specifications for the biodiversity index and countries are sufficiently symmetric such that $I = 0$ holds. With endemic species, a marginal reallocation of capital from North to South will lead to an increase (decrease) of habitat area in the North (South).

Making use of these insights with respect to the biodiversity index, we can formulate the following results.

Result 2 *Under an exogenous marginal increase in North-South investment ($dI > 0$), and excluding the diversity-induced substitution effect, North (South) should increase (decrease) habitat conservation, provided the initial level of foreign investment is sufficiently small.*

Result 3. *The specific functional form of the global biodiversity index determines the optimal response. Under strict species endemism, $b_{s^*s} = b_{ss^*} = 0$, the diversity-induced substitution effect (via D and D^*) completely disappears.*

Interestingly, the diversity-induced substitution effect (through D and D^*) is not present under high species endemism. The reason is that the initial increase in habitat area in North, following increased North-South investment, is now a pure gain: there is no overlap between the species "won" and existing species in South. In other words, under full species endemism South has no incentive to free ride on efforts in North by decreasing its habitat area to get rid of 'redundant' species. Mathematically, the marginal benefit of local species ($\eta^* b_{s^*}$) equals the marginal benefit of biodiversity (η^*) and is thus independent of s. High levels of redundancy on the other hand increase the strength of the beforementioned substitution effect and essentially provide a drive towards specialization: one region as a large reserve site, the other dedicated to production (For an analysis of this issue in a framework of the new economic geography, see Barbier and Rauscher, 2007).

We should stress that the diversity-induced substitution effect is different from the traditional free-rider effect that characterizes many public goods related problems. Free-rider effects arise when the damages of a public bad (or the benefits of a public good) are strictly convex (concave) in the sum of the contributions. For example, in the case of greenhouse gasses free-rider effects arise when the damage function is strictly convex in global emissions; in that case the marginal damage of emissions is increasing in global emissions. In that case any unilateral effort to reduce emissions will lower the marginal damage of emissions abroad which gives rise to self-interested increases in emissions in other countries. Here the marginal damage of biodiversity is constant and the diversity-induced substitution effect originates in the fact that species in different countries are imperfect substitutes.

2.5 Land Policy in General Equilibrium and Tax Competition

2.5.1 A Cooperative Solution

We start out by analyzing a cooperative solution where North and South maximize global welfare by (i) allocating capital across countries and (ii) in each country allocate land between production purposes and habitat conservation. We impose a set of restrictions which states that in each country consumption equals national income. The reason for this is as follows. In the appendix we show that the social optimum is characterized by four efficiency conditions. Among these efficiency conditions is the equalization of the marginal utility of consumption across countries. A sufficient condition to implement the social optimum in a market economy is the use of at least four instruments. Usually this means that one will use international transfers to guarantee the beforementioned efficiency condition. We view international lump-sum transfers as politically infeasible and therefore view our cooperative solution as a more useful benchmark to which we can compare the outcome of the non-cooperative solution in the next section. Thus, we consider the second-best solution.

We maximize the sum of welfare $V + V^*$ with respect to the allocation of land and investment, subject to a set of budget restrictions, a restriction on international investment, stock constraints on land and abstract from capital market frictions ($\rho = 0$):

$$\max_{\{I,T_M,T_M^*\}} u(C) + u(C^*) + \eta b(s(T_H), as^*(T_H^*)) + \eta^* b^*(As(T_H), s^*(T_H^*)) \tag{2.28}$$

subject to

$$C = f(K_0 - I, L, T_M) + f_K^* I \quad , \quad C^* = f(K_0^* + I, L^*, T_M^*) - f_K^* I \tag{2.29}$$

$$T = T_H + T_M \quad , \quad T^* = T_H^* + T_M^* \tag{2.30}$$

$$-K_0^* \leq I \leq K_0 \tag{2.31}$$

After substitution of conditions (2.29)-(2.30) into the objective function this becomes an unconstrained maximization problem with respect to three variables. We can drop the restriction on investment (2.31) since the Inada conditions assure an interior solution. Maximization yields the following set of first-order conditions:

$$u_C[f_K^* - f_K + f_{KK}^* I] = u_C^*[f_{KK}^* I] \tag{2.32}$$

$$u_C f_T = (\eta b_s + a\eta^* b_s^*) s_T \tag{2.33}$$

$$u_C^*[f_T^* - f_{KT}^* I] = (\eta^* b_{s^*}^* + A\eta b_{s^*}) s_T^* \tag{2.34}$$

It is evident that, in contrast to the first-best, the second-best solution does not entail equalization of the marginal utility from consumption across North and South. Equation (2.32) states that the marginal return on capital in util terms should be equalized across countries. This is fundamentally different from the market solution, where capital owners seek to maximize their net return on capital.

In principle, there are four qualitatively different types of factor allocations such that (2.32) holds with equality:

1. $I > 0$, $f_K^* < f_K$.
2. $I > 0$, $f_K^* > f_K$; which requires $f_K^* - f_K + f_{KK}^* I < 0$.

3. $I < 0$, $f_K^* > f_K$.
4. $I < 0$, $f_K^* < f_K$; which requires $f_K^* - f_K + f_{KK}^* I > 0$.

Since $C = Y = Q + f_K^* I$ and $C^* = Y^* = Q^* - f_K^* I$, allocations (1) and (3) correspond to the situation where national income in North is higher than in South, $\frac{u_C}{u_C^*} < 1 \Leftrightarrow Y > Y^*$. Similarly, allocations (2) and (4) correspond to South having a higher national income than North, $\frac{u_C}{u_C^*} > 1 \Leftrightarrow Y < Y^*$. Interestingly, from equation (2.32) we can also learn whether the second-best solution ceteris paribus implies a greater reallocation of capital from North to South than would be optimal in either the first best or in a market economy, where the condition $f_K = f_K^*$ must hold. Let us center the discussion around case (1) and (2) with positive North-South investment, $I > 0$. Case (1), which corresponds to $Y > Y^*$, seems to indicate that the reallocation of capital in the second-best is larger than in the first best, since $f_K > f_K^*$. Case (2), however, where $Y < Y^*$, suggest that the reallocation of capital in the second-best is actually smaller than in the first best, since $f_K < f_K^*$. Interestingly, from case (2) and (3) we also learn that in principle we can not exclude the possibility that in the second-best solution capital will flow from the low income to the high income country.

Equations (2.33)-(2.34) represent the Samuelson conditions for the (optimal) provision of biodiversity in North and South respectively. To see how they are 'distorted' under the second-best solution, let us rewrite (2.33) and (2.34) with the use of (2.32) to obtain:

$$\frac{f_T}{s_T} = \frac{\eta b_s}{u_C} + \frac{a\eta^* b_s^*}{u_C^*} + \frac{f_K^* - f_K}{f_{KK}^* I}\frac{a\eta^* b_s^*}{u_C^*} \tag{2.35}$$

$$\frac{f_T^*}{s_T^*} = \frac{\eta^* b_{s^*}^*}{u_C^*} + \frac{A\eta b_{s^*}}{u_C} - \frac{f_K^* - f_K}{f_K^* - f_K + f_{KK}^* I}\frac{A\eta b_{s^*}}{u_C} + \frac{f_{KT}^* I}{s_T^*} \tag{2.36}$$

To interpret this equations let us focus on the provision of biodiversity in the South via (2.36). The term $\frac{f_T^*}{s_T^*}$ on the left-hand side of (2.36) represents the marginal transformation between the consumption good and species in the South. An alternative and equally valid interpretation is the marginal cost of providing an additional specie. On the right-hand side of (2.36) the first two terms represent the sum of the marginal rate of substitution between consumption and biodiversity in North and South respectively. The sum of these two terms can also be expressed as the global marginal willingness to pay for Southern biodiversity conservation, $-(\frac{V_{s^*}^*}{V_Y^*} + \frac{V_{s^*}}{V_Y})$. These terms are present in the first-best solution as well.

The provision of biodiversity is distorted in two different ways compared to the social optimum. First, the global marginal willingness to pay is altered compared to the first best due to additional terms, $\frac{f_K^* - f_K}{f_{KK}^* I}\frac{a\eta^* b_s^*}{u_C^*}$ and $-\frac{f_K^* - f_K}{f_K^* - f_K + f_{KK}^* I}\frac{A\eta b_{s^*}}{u_C}$ for North and South respectively, that complement the first-best terms. Define the second-best marginal willingness to pay for biodiversity in North (South) as $WTP_N^{SB} \equiv \frac{\eta b_s}{u_C} + \frac{a\eta^* b_s^*}{u_C^*} + \frac{f_K^* - f_K}{f_{KK}^* I}\frac{a\eta^* b_s^*}{u_C^*}$ ($WTP_S^{SB} \equiv \frac{\eta^* b_{s^*}^*}{u_C^*} + \frac{A\eta b_{s^*}}{u_C} - \frac{f_K^* - f_K}{f_K^* - f_K + f_{KK}^* I}\frac{A\eta b_{s^*}}{u_C}$). Then we find that $WTP_N^{SB} \gtrless \frac{\eta b_s}{u_C} + \frac{a\eta^* b_s^*}{u_C^*}$ and $WTP_S^{SB} \lesseqgtr \frac{\eta^* b_{s^*}^*}{u_C^*} + \frac{A\eta b_{s^*}}{u_C}$ for $Y \gtrless Y^*$. In words, if income in North is higher than in South then the global marginal willingness to pay for biodiversity in North is ceteris paribus higher than in the first-best and the global marginal willingness to pay for biodiversity in South is ceteris paribus lower than in the first-best. An opposite result holds if income in South is higher than in North. Note that in general we find that the Northern marginal willingness to pay,

$\frac{A\eta b_{s*}}{u_C} - \frac{f_K^* - f_K}{f_K^* - f_K + f_{KK}^* I} \frac{A\eta b_{s*}}{u_C}$, is different than in the first-best not only because of the additional term $-\frac{f_K^* - f_K}{f_K^* - f_K + f_{KK}^* I} \frac{A\eta b_{s*}}{u_C}$ but also because the marginal utility of consumption is different. In the first-best we find $Y = Y^*$ which in general is not the case for the second-best. If $Y > Y^*$ then the marginal willigness to pay for biodiversity tends to be higher in North than in South compared to the social optimum. Second, the marginal rate of transformation between consumption and biodiversity in South, $\frac{f_T^*}{s_T^*} - \frac{f_{KT}^* I}{s_T^*}$, is adjusted downwards due to the term $\frac{f_{KT}^* I}{s_T^*}$. This effect tends to lower the marginal cost of biodiversity in South. The intuition is simple: stringent land policy lowers the return on foreign investment and these costs are borne by the North, not the South.

The overall effect of these two distortions in (2.36) on the provision of biodiversity in the South is ambiguous: it is unclear whether the provision of this public good is higher or lower than in the social optimum. As explained, for the North we find only one additional term in the Samuelson condition, equation (2.35), which tends to raise (lower) the global marginal willingness to pay for Northern biodiversity conservation if $Y > Y^*$ ($Y < Y^*$). This implies that in general one would expect that biodiversity in North is higher (lower) than in the social optimum if $Y > Y^*$ ($Y < Y^*$).

2.5.2 Comparing Biodiversity in the First-best and in the Second-best

In the appendix we show that the first-best is characterized by (i) equalization of the marginal cost of conservation across North and South, $\frac{f_T}{s_T} = \frac{f_T^*}{s_T^*}$ (allocative efficiency of land), (ii) equalization of the marginal rate of substitution between biodiversity and consumption across North and South (consumption efficiency), provided $a = A$ and $\eta = \eta^*$, and (iii) equalization of the marginal utility of consumption. Together they imply product-mix efficieny, that is, $\frac{f_T}{s_T} = \frac{f_T^*}{s_T^*} = \frac{\eta b_s}{u_C} + \frac{\eta^* b_s^*}{u_C^*} = \frac{\eta^* b_{s*}^*}{u_C^*} + \frac{\eta b_{s*}}{u_C}$. These efficiency conditions do not imply, however, that the level of biodiversity in the first-best is independent of the initial allocation of the factors of production. In general, levels of world production, consumption and biodiversity will vary with the initial allocation of labor. This is due to two reasons. First, land is immobile and we have abstracted from labor mobility (i.e. ignored labor migration), implying that only one out of three factors of production, capital, can be reallocated across countries. Second, in a neoclassical world we find that, due to diminishing returns to each factor of production, an uneven initial allocation of labor will ceteris paribus lower world production. Capital mobility can only partially undo the factor allocation inefficiency that arises due to the immobility of labor.

In the absence of labor migration, what is the effect of an uneven allocation of labor, for given endowments of land, on the provision of biodiversity? There are two effects, a demand effect and a supply effect. First, note that in the first-best the equalization of the marginal utility of consumption implies $C = C^* = \frac{1}{2}(Q + Q^*) \equiv \frac{1}{2}Q^w$. This implies that the higher the level of world production Q^w, the higher the marginal willigness to pay for biodiversity conservation (via u_C). Thus, uneven allocations of labor tend to lower world production and world income, thereby lowering the demand for biodiversity. This is the demand effect. Second, an uneven allocation of labor will drive a wedge between the marginal productivity of land in North and South ($f_T \neq f_T^*$), which would otherwise be equalized in the first-best with labor migration. In words, since it is relatively efficient (inefficient) to conserve habitat in the country with a low (high) population density, habitat conservation tends to increase (decrease) in the country with a low (high) population density. This is the supply effect. In conclusion, it is unclear whether the global level of biodiversity increases or decreases in the 'first-best' if the initial allocation of labor becomes more dispersed.

2.5.3 Capital Allocation under Cooperation

Some further insights in the global allocation of capital can be attained by dividing the Samuelson condition for the North by the Samuelson condition for the South:

$$\frac{f_T}{f_T^* - f_{KT}^* I} = \frac{(\eta b_s + a\eta^* b_s^*)/u_C}{(\eta^* b_{s^*}^* + A\eta b_{s^*})/u_C^*} \frac{s_T}{s_T^*} \tag{2.37}$$

which gives us the relationship between the relative productivity of land ($\frac{f_T}{f_T^* - f_{KT}^* I}$) and the relative marginal willingness to pay for habitat conservation ($\frac{(\eta b_s + a\eta^* b_s^*)/u_C}{(\eta^* b_{s^*}^* + A\eta b_{s^*})/u_C^*}$), corrected for the relative productivity of habitat $\frac{s_T}{s_T^*}$. Rewriting (2.37) once more yields:

$$I = \frac{f_T}{f_{KT}^*} \frac{\Omega^T \frac{\tau}{\tau^*} \frac{s_T}{s_T^*} - 1}{\frac{\tau}{\tau^*} \frac{s_T}{s_T^*}} \tag{2.38}$$

where $\Omega^T \equiv f_T^*/f_T$ represents the South-North ratio of the marginal productivity of land and $\tau = \frac{\eta + a\eta^*}{u_C} b_s$ ($\tau^* = \frac{\eta^* + A\eta}{u_C^*} b_{s*}$) represents a marginal damage term from biodiversity loss in the North (South). To build intuition, note that if $u_C = u_C^*$ these terms are identical to the global marginal damage from biodiversity loss in a particular region. Note that equation (2.38) is an implicit equation in I; the term on the right-hand side also depends on I. In case of a Cobb-Douglas functional form, as in our leading example, equation (2.38) can be written as $I = \frac{1}{\beta}(K_0^* + I) \frac{\left(\frac{T_M^*}{T_M}\right) \frac{\tau}{\tau^*} \frac{s_T}{s_T^*} - (\frac{L}{L^*})^\alpha (\frac{K_0 - I}{K_0^* + I})^\beta (\frac{T_M}{T_M^*})^{\chi - 1}}{\frac{\tau}{\tau^*} \frac{s_T}{s_T^*}}$, where $l \equiv L/L^*$ is the North-South population ratio.

From (2.38) we can show that an equilibrium with positive investment, i.e. capital flows from North to South, is equivalent to the following condition:

$$I > 0 \Leftrightarrow \Omega^T > \frac{\tau^*}{\tau} \frac{s_T^*}{s_T} \tag{2.39}$$

If the relative productivity of land in the South (Ω^T) exceeds the South-North ratio of the social marginal damage from biodiversity loss ($\frac{\tau^*}{\tau}$), corrected for the relative productivity of ecosystems ($\frac{s_T^*}{s_T}$), then investment is positive. Thus, it is optimal to relocate capital from North to South if the relatively productivity of land in the South is higher than the relative global marginal benefit from habitat conservation in the South.

Example *Assume the functional forms as in our leading example (although with linear utility instead of log-utility), with $\varphi = 1$, $V = C + \eta(s + as^*)$ and $V^* = C^* + \eta^*(As + s^*)$. Define $g \equiv \frac{\kappa^*}{\kappa} \frac{A\eta + \eta^*}{\eta + a\eta^*} \frac{1}{K_0^* + K_0}$, $h \equiv (\alpha + \beta)/\chi g(l)^{-\frac{\alpha}{\beta}}$ and $z \equiv \frac{T_M^*}{T_M}$. Then in the appendix we show that the solution to z is implicitly* *defined by* $z^{1-\chi} = g(K_0+1)+g\beta l^{-\frac{\alpha}{\beta}} z^{\frac{\chi}{\beta}}$. *If* $1-(1+\beta)(\alpha+\beta) > 0$ *then there exists a unique solution* $\tilde{z}$ *which satisfies* $\tilde{z} > \bar{z}$, *where* $\bar{z} \equiv h^{\frac{\beta}{1-(1+\beta)(\alpha+\beta)}}$. *The condition for positive investment (2.39) then reads:*

$$\tilde{z} > \frac{\kappa}{\kappa^*} \tag{2.40}$$

Suppose the North (South) is relatively scarce (abundant) in the endowment of land and the South is also relatively poor compared to the North. In the absence of international transfers, and with an abundant supply of land in the South, social welfare will benefit from an inflow of capital to the South. Stated otherwise, since the North is so resource scare social welfare benefits from a reallocation of capital to the resource abundant South. Thus, global welfare is maximized by by moving mobile factors of production to these regions where immobile factors are in abundant supply.

2.5.4 Investment in a Market Economy and Implementing the Cooperative Solution

Next, let us analyze the conditions for positive investment in a market economy. We assume exogenous land policies in each country and again take Cobb-Douglas functional forms from our leading example. Then use $f_K = f_K^*$ to solve for $\frac{T_M}{T_M^*}$ as a function of I, L, L^*, K_0 and K_0^*, that is, $\frac{T_M}{T_M^*} = \frac{T_M}{T_M^*}(I)$. We can then solve for I by substitution of $\frac{T_M}{T_M^*}(I)$ into $\frac{f_T}{f_T^*} = \frac{t_M}{t_M^*}$ and rearrange to obtain:

$$I = \frac{t^{\Phi} K_0 - K_0^* l}{l + t^{\Phi}} = \frac{t^{\Phi} k_0 - k_0^*}{l + t^{\Phi}} L \tag{2.41}$$

where $t \equiv t_M/t_M^*$ is the North-South land-tax ratio, $k_0 \equiv K_0/L$, $k_0^* \equiv K_0^*/L^*$ and $\Phi \equiv (1-\alpha-\beta)/\alpha = \chi/\alpha$ is the ratio of the share of land in production over the share of labor in production. From (2.41), equilibrium investment is increasing in the initial Northern capital stock (K_0), decreasing in the Southern capital stock (K_0^*) and increasing in the relative stringency of North-South land policy t.

In a market economy, a necessary condition for I to be positive, that is, to have capital flowing from the North to the South, is the denominator being positive, $l + t^{\Phi} > 0$, which is always guaranteed. Thus, a sufficient and necessary condition in a market economy for positive investment in equilibrium is a positive numerator, that is, $t^{\Phi} k_0 - k_0^* > 0$. Rewriting gives us the intuitive condition that the Northern capital-labor ratio k must be larger than the Southern capital-labor ratio k^*, controlled for the land-tax ratio and the consumption price in the South:

$$t^{\Phi} > \frac{k_0^*}{k_0}$$

With identical land policies in North and South, this condition boils down to a standard factor-endowment result where the capital-rich country exports capital: $k_0 > k_0^* \Leftrightarrow I > 0$. Since land-policy is taken as given in this exercise, the fundamental determinant in this model is the North-South capital-labor ratio. It also shows that if domestic land policy is sufficiently stringent even a capital-poor country can become an exporter of capital in a market economy since land will be de-facto scarce.

It is feasible to implement the second-best solution discussed in section 5.1 in a market economy.

Since the second-best solution is characterized by three equations, (2.32)-(2.34), we need at least three market instruments to implement this solution. First, using the Samuelson conditions for the provision of habitat area, (2.35)-(2.36), we can derive the taxes on land:

$$t_M^C = f_T = \left(\frac{\eta b_s}{u_C} + \frac{a\eta^* b_s^*}{u_C^*} + \frac{f_K^* - f_K}{f_{KK}^* I} \frac{a\eta^* b_s^*}{u_C^*} \right) s_T \tag{2.42}$$

$$t_M^{*C} = f_T^* = \left(\frac{\eta^* b_{s^*}^*}{u_C^*} + \frac{A\eta b_{s^*}}{u_C} - \frac{f_K^* - f_K}{f_K^* - f_K + f_{KK}^* I} \frac{A\eta b_{s^*}}{u_C} + \frac{f_{KT}^* I}{s_T^*} \right) s_T^* \tag{2.43}$$

Free mobility of capital in a market economy implies $f_K^* = f_K$, which means that without additional policies the taxes on land in (2.42)-(2.43) differ from their second-best levels. To get rid of this "distortion", we first rearrange (2.32) to obtain $f_K^* - f_K = \left(\frac{u_C^*}{u_C} - 1 \right) f_{KK}^* I$. Now suppose that the government in North (South) can set a tax rate t_K (t_K^*) on the use of capital in production, which is paid by producers. Using the new market location condition of capital, $f_K - t_K = f_K^* - t_K^*$, we can now show that countries should set taxes on capital (and distribute them lump-sum) such that the following condition holds:

$$t_K^* - t_K = \left(\frac{u_C^*}{u_C} - 1 \right) f_{KK}^* I \tag{2.44}$$

The combination of (2.42)-(2.43) and (2.44) implements the second-best solution. Note that as long as $\frac{u_C^*}{u_C} > 1$, implying that the South consumes less than the North, the tax differential should be negative, $t_K^* - t_K < 0$.

2.5.5 The Non-Cooperative Solution

Now that we have determined the cooperative solution for land policy let us evaluate the non-cooperative solution. When we consider a setting with two countries a country's policies might alter the renumeration (interest rate) to capital. The incentive to use land policy as a means to alter the interest rate, introduces an additional distortion which has implications for conservation. We show how this distortion has different implications for North and South.

So to be able to consider capital market interactions, we repeat the following 'location condition' of capital:

$$f_K(K_0 - I, L, T_M) = f_K^*(K_0^* + I, L^*, T_M^*) \tag{2.45}$$

Both countries are able to influence the location of capital by setting a lax policy with respect to land. In what follows we determine the non-cooperative solution under the assumption that both countries take the other's tax policies as given (Nash equilibrium). Thus, we consider a non-cooperative game with one instrument. The necessary first-order conditions are:

$$\frac{\partial V}{\partial T_M} = u_C \frac{dC}{dT_M} + \eta \frac{db}{dT_M} = 0 \quad , \quad \frac{\partial V^*}{\partial T_M^*} = u_C^* \frac{dC^*}{dT_M^*} + \eta^* \frac{db^*}{dT_M^*} = 0 \tag{2.46}$$

where $\frac{dC}{dT_M} = f_T + f^*_{KK} I \frac{dI}{dT_M}$ and $\frac{dC^*}{dT^*_M} = f^*_T - f^*_{KK} I \frac{dI}{dT^*_M}$. Differentiating (2.45) results in $\frac{dI}{dT_M} = \frac{f_{KT}}{f_{KK}+f^*_{KK}} < 0$ and $\frac{dI}{dT^*_M} = -\frac{f^*_{KT}}{f_{KK}+f^*_{KK}} > 0$. Substitution of these results into (2.46) and rewriting yields the non-cooperative taxes on land:

$$t^{NC}_M = f_T = \frac{\eta b_s s_T}{u_C} - \frac{f^*_{KK} f_{KT} I}{f_{KK} + f^*_{KK}} \quad , \quad t^{*NC}_M = f^*_T = \frac{\eta^* b_s s^*_T}{u^*_C} + \frac{f_{KK} f^*_{KT} I}{f_{KK} + f^*_{KK}} \tag{2.47}$$

Now let us compare the non-cooperative taxes in (2.47) with the cooperative taxes in (2.42)-(2.43). When countries are fully symmetric we find $I = 0$ and the cooperative solution (second-best) coincides with the social optimum. In that case, the cooperative taxes equal the social marginal benefit from habitat conservation (Pigouvian taxes). The non-cooperative taxes, however, differ from the cooperative taxes by the fact that they only internalize the regional, not global, benefits from regional conservation. Thus, under symmetry the second-best solution is characterized by stricter land taxes than the non-cooperative solution, that is, $t^C_M > t^{NC}_M$ and $t^{*C}_M > t^{*NC}_M$. Global biodiversity is higher under the cooperative solution than the non-cooperative solution.

With asymmetric countries the comparison between cooperative and non-cooperative taxes is more complicated. Again, in the non-cooperative solution countries only internalize the domestic benefits from domestic conservation. The North also has an incentive to loosen its domestic land policy in order to increase the rents from international investment, $r^* I$, whereas the South on the other hand has an incentive to impose stricter land policy to reduce its capital payments to North. These effects are represented by the additional terms in (2.47), $-\frac{f^*_{KK} f_{KT} I}{f_{KK}+f^*_{KK}} < 0$ and $\frac{f_{KK} f^*_{KT} I}{f_{KK}+f^*_{KK}} > 0$ for North and South respectively. Due to these effects, ceteris paribus taxes will be higher (lower) in the South (North).

The last difference between the two solutions is that under the cooperative solution both the allocation of capital and the land taxes are used as instruments to redistribute income across countries. Although the social welfare function ($V + V^*$) is neutral with respect to inequality aversion, equation (2.32) indicates that capital is reallocated such to equalize the marginal return on capital in util terms. Compared to the market outcome, this will lead to a greater reallocation of capital from North to South. Similarly, the land tax in the North (South) tends to be set above (below) the Pigouvian level (see the 3th term in (2.42)-(2.43)) in order to stimulate (attract) North-South investment. This tends to raise (lower) the tax in the North (South) and increase (lower) biodiversity in the North (South). An overal comparision between the cooperative taxes and non-cooperative taxes gives ambiguous results:

Result 4 *For symmetric countries the Nash-equilibrium yields unambiguously lower land taxes in both countries when compared to the cooperative setting. As a result of these lower taxes biodiversity is underprovided in the non-cooperative setting. In case of asymmetric countries, for the North the non-cooperative tax is unambiguously lower than the cooperative tax. For the South the comparision between the cooperative and non-cooperative tax is inconclusive.*

That the non-cooperative tax for the North is lower than the cooperative tax implies that biodiversity in the North tends to be underprovided under the non-cooperative solution (absent any income effect considerations). For the South we find ambiguous results. The reason is that the cooperative tax for the South includes an income redistribution term that tends to lower the tax on land. There is also a remittances effect: stringent land policy diminishes the flow of capital payments to foreigners. This consideration tends to increase the cooperative land tax. The non-cooperative tax on the other hand also includes a remittances term that ceteris paribus increases the tax on land. A comparison of all the various effects under the two solutions provides for an inconclusive outcome.

The underprovision of public goods when jurisdictions compete in taxes is a well-known result in the literature on optimal taxation (Oates and Schwabb, 1988; Flatters et al., 1974). A difference is that in the problem analyzed here, regions compete in taxes set on a cooperative factor of production, and not on capital itself. Other differences with Oates and Schwabb (1988) are the possible asymmetry of regions and the inclusion of a remittances effect as a result thereof.

Under tax competition countries do not internalize the positive externalities of a higher tax on land. Local habitat protection benefits the other country as well, although to a lesser extent. If countries are asymmetric for any of the reasons mentioned earlier (preferences, endowments), then there is an extra externality involved. This externality represents the beneficial effects of a better factor allocation for both countries (capital market effect or remittances effect). The Nash equilibrium yields unambiguously lower taxes for countries that are ‘sufficiently symmetric’ and underprovision of global biodiversity results.

2.6 Environmental Kuznets Curve for Biodiversity and Land Regulation?

In our model environmental policy is modelled in a relatively simply manner: the government either sets a land tax or a quota. Although we considered optimal policies, we have not yet analyzed the effects of capital market liberalization under endogenous policy. To model an endogenous policy response to capital market liberalization, we take a small open economy facing an exogenous world interest rate r^w and analyze how investment affects land-use. We assume that the South is not fully integrated in world capital markets which we capture by the parameter $\rho > 0$:

$$r = f_K^*(K_0^* + I, L^*, T_M^*) = (1+\rho)r^w \tag{2.48}$$

In what follows we assume that an exogenous fall in ρ captures integration in world capital markets and, ceteris paribus, will foster inflow of investment. Since investment unambiguously raises income, we use a logarithmic utility function to emphasize the role of income gains in environmental policy:

$$V^* = \ln(C^*) + \eta^* b(As(T - T_M), s^*(T^* - T_M^*)) \tag{2.49}$$

with $C^* = Y^* = Q^* - rI$. Optimal land policy follows from the first-order condition $\frac{dV^*}{dT_M^*} = 0$, which can be rearranged to

$$\frac{V_{s^*}^*}{V_I^*} = -\frac{dI/dT_M^*}{ds^*/dT_M^*} = -\frac{dI}{ds^*} \tag{2.50}$$

The left-hand side $\frac{V^*_{s^*}}{V^*_I}$ measures the marginal willingness to pay for biodiversity conservation. Using (2.49) we find $\frac{V^*_{s^*}}{V^*_I} = \eta^* b_{s^*} Y^*$, which is rising with income. The right-hand side of (2.50) measures the marginal rate of transformation between income and species richness. Again, using (2.49) this becomes $-\frac{dI}{ds^*} = \frac{f^*_T(K^*_0+I,L^*,T^*_M)}{s^*_T(T-T^*_M)}$. Using $\frac{V^*_{s^*}}{V^*_I} = \eta^* b_{s^*} Y^*$ and $-\frac{dI}{ds^*} = \frac{f^*_T(K^*_0+I,L^*,T^*_M)}{s^*_T(T-T^*_M)}$ one can reinterpret (2.50) by rearranging this equation as

$$f^*_T(K^*_0 + I, L^*, T^*_M) = \eta^* b_s(As(T - T_M), s^*(T^* - T^*_M))s^*_T(T - T^*_M)Y^* \tag{2.51}$$

Equation (2.51) states that the optimal land policy equates the marginal productivity of land to the marginal willingness to pay for land preservation. In other words, the government must either set a tax $t^*_M = f^*_T$ or implement a quota T^*_M such that (2.51) holds. As explained in Copeland and Taylor (2003), the marginal willingness to pay is also known as "marginal damage" in the environmental economics literature. Thus, one can write $f_T(K^*_0 + I, L^*, T^*_M) = MDB^*(T_M, T^*_M, Y^*)$, where $MDB^*(T_M, T^*_M, Y^*) \equiv \eta^* b_s(As(T - T_M), s^*(T^* - T^*_M))s^*_T(T - T^*_M)Y^*$, the marginal damage to biodiversity from a decrease in habitat area.

Next, differentiating (2.51), (2.48) and $Y^* = Q^* - rI$ with respect to T^*_M, I and ρ yields the marginal change in land use due to a marginal change in capital market frictions under an endogenous policy response:

$$\frac{dT^*_M}{d\rho} = \frac{t^*_M}{I}\frac{\varepsilon^*_{MDB,Y}\varepsilon^*_{Y,I} - \varepsilon_{t_M,I}}{\Theta} r^w \tag{2.52}$$

$$\frac{dI}{d\rho} = \frac{r^w}{f^*_{KK}} - \frac{f^*_{KT}}{f^*_{KK}}\frac{dT^*_M}{d\rho} \tag{2.53}$$

where $\varepsilon^*_{MDB,Y} \equiv \frac{dMDB^*}{dY^*}/\frac{MDB^*}{Y^*}$ represents the elasticity of marginal damage to biodiversity with respect to income, $\varepsilon^*_{Y,I} \equiv \frac{dY^*}{dI}/\frac{Y^*}{I}$ is the elasticity of national income with respect to investment, $\varepsilon_{t_M,I} \equiv \frac{f^*_{TK}I}{t^*_M} = \frac{df_T}{dI}\frac{I}{f_T}$ represents the elasticity of inverse land demand with respect to a change investment, $\Theta \equiv (f^*_{TT}f^*_{KK} - f^*_{KT}f^*_{TK}) - MDB^*_Y f^*_{KK} I - f^*_{KK}(MDB^*_Y f^*_T - MDB^*_T)$, $MDB^*_Y \equiv \eta^* b_{s^*} s^*_T > 0$ and $MDB^*_T \equiv \eta^*[b_{s^*s^*}(s^*_T)^2 + b_{s^*}s^*_{TT}]Y^* < 0$. In general the sign of the derivative is ambiguous, since the sign of the numerator is not clear[8]. For $\varepsilon^*_{MDB,Y}\varepsilon^*_{Y,I} - \varepsilon_{t_M,I}$ to be positive, we must have $\varepsilon^*_{MDB,Y}\varepsilon^*_{Y,I} > \varepsilon_{t_M,I}$, which depends not only on preferences such as η^*, but also on the size of the investment flow I and the strength of an increase in investment on the demand for land f^*_{TK}. Thus, a decrease in the world interest rate is likely to raise the demand for land if the marginal damage from biodiversity loss is low, the size of total foreign direct investment is low and the share of land in production is small. Now use $\varepsilon^*_{MDB,Y} = 1$, $\varepsilon^*_{Y,I} = -f^*_{KK} I \frac{I}{Y^*}$, $\varepsilon_{t_M,I} = \frac{f^*_{TK}I}{\eta^* b_{s^*} s^*_T Y^*}$ and (2.52) to obtain:

$$\frac{dT^*_M}{d\rho} \gtrless 0 \Leftrightarrow \eta^* b_{s^*} s^*_T \gtrless -\frac{f^*_{KK}}{f^*_{TK}} I$$

[8]Note that we can sign the denominator, $\Delta > 0$, provided the own second-order derivatives of the production function are larger than the cross-derivatives such that $f^*_{TT}f^*_{KK} - f^*_{KT}f^*_{TK} > 0$.

Note that one can not exclude the possibility of the derivative changing signs, that is, for sufficiently large inflows of investment the demand for habitat area increases. The intuition is that since the marginal damage from biodiversity increases with income, large enough income gains from investment may increase the demand for biodiversity at the cost of land usage in production.

2.7 Conclusions

In this chapter we described a simple model of economic integration where consumers care about both local and global levels of biological diversity. Since biodiversity and aggregate production both depend on the use of land, there is an inherent trade-off in this economy between habitat conservation one the hand and consumption on the other hand. We discussed issues of cooperative and non-cooperative land policies, capital market liberalization and changes in biodiversity.

A small open economy that takes the world interest rate as given attracts capital from abroad if it is relatively poor in capital and/or its land policy is relatively lax. Liberalization improves production, increases utility from consumption and improves overall welfare if land policy is optimal. Only with a strict quota on land is the original size of habitat maintained. If there is a tax on land use, then biodiversity unambiguously declines but this may be desirable in terms of overall welfare if the tax rate itself is optimal.

Next, we discussed some strategic issues concerning land policies. It was found that a global drop in ecosystem productivity, for example due to climate change, is more likely to increase habitat area than a purely local shock. Furthermore, we found that ecological characteristics play an important role in setting land policies as well. If there is a degree of redundancy, implying that many species inhabit both North and South, there is more room for strategic interaction. Under these circumstances, governments weaken their land policies if there is a marginal increase in habitat area abroad, since governments calculate that now more species at home are redundant from a global point of view.

We also strengthened our intuition regarding the condition required for positive capital investment from North to South in a market economy. A relatively land abundant country can 'de-facto' be a relatively land scarce country if its land policy in the form of a quota or tax is sufficiently stringent. This 'de-facto' endowment condition was found before by Rauscher (1997) in the context of trade and pollution. It basically entails a combination of the 'pollution haven hypothesis' and the 'factor endowment hypothesis'. If the land-tax ratio is equal to one, we obtain a classic factor endowment result.

We also raised questions concerning social welfare under cooperation. We analyzed a second-best cooperative solution where international transfers were assumed absent. In the cooperative solution, as in a market economy, capital is allocated to regions where it is in short supply. In general, the cooperative solution will be characterized by a more extensive reallocation of capital than in a market economy. This is because in the absence of international transfers, the allocation of investment is also used to redistribute income across countries. A similar argument holds for conservation policies. It is found that there is a tendency to use weaker conservation policy in the South than in the North in order to redistribute income. Global biodiversity conservation attains a higher level under the cooperative solution than under the non-cooperative solution if countries are symmetric. With asymmetric countries the comparision between cooperation and non-cooperation does not provide for clearcut answers which is again related to the income redistribution argument that plays a role under the cooperative solution.

Furthermore, we investigated the possibilities of an environmental Kuznets curve for biodiversity. To do so, we derived comparative statics for capital market liberalization under endogenous land policy. By taking a simple log-linear functional form for utility, the land-tax or quota was shown to be increasing in income. Our experiment assumed a drop in capital market frictions that would give rise to a surge of international investment in the South. Even though this rise in income is associated with an immediate increase in the stringency of land policy, the effect on local habitat conservation and biodiversity is ambiguous. The chance of an improvement in biodiversity increases with (i) the elasticity of marginal damage from biodiversity loss and decreases with (ii) the share of land in production, among other factors.

2.8 Appendix

Comparative Statics of Capital Market Integration

We totally differentiate the first-order conditions for optimal land-policy (2.23) and the location condition in (2.22) with respect to T_M, T_M^*, I and ρ to obtain the following set of equations:

$$\frac{dI}{d\rho} = \frac{f_K - f_{KT}^* \frac{dT_M^*}{d\rho} + (1+\rho) f_{KT} \frac{dT_M}{d\rho}}{f_{KK}^* + (1+\rho) f_{KK}} \tag{2.54}$$

$$\frac{dT_M}{d\rho} = \frac{\left(u_{CC} f_T f_{KK} I + u_C f_{TK} - \eta b_{ss*} s_T s_T^* \frac{dT_M^*}{dI}\right) \frac{dI}{d\rho}}{u_{CC} f_T (f_T + f_{KT} I) + u_C f_{TT} + \eta (b_{ss}(s_T)^2 + b_s s_{TT})} \tag{2.55}$$

$$\frac{dT_M^*}{d\rho} = \frac{u_{CC}^* f_T^* \left(f_{KK}^* (\frac{\rho}{1+\rho} K_0^* + I) \frac{dI}{d\rho} + \frac{1}{(1+\rho)^2} f_K^* K_0^*\right) - u_C^* f_{TK}^* \frac{dI}{d\rho} - \eta^* b_{s*s} s_T s_T^* \frac{dT_M}{dI} \frac{dI}{d\rho}}{u_{CC}^* f_T^* (f_T^* - f_{KT}^* \left(\frac{\rho}{1+\rho} K_0^* + I\right)) + u_C^* f_{TT}^* + \eta^* (b_{s*s*}(s_T^*)^2 + b_{s^*} s_{TT}^*)} \tag{2.56}$$

Simplifying notation such that $\frac{dI}{d\rho} = (G - H \frac{dT_M^*}{d\rho} + N \frac{dT_M}{d\rho})/E$, $\frac{dT_M}{d\rho} = (Z \frac{dI}{d\rho} - D \frac{dT_M^*}{d\rho})/X$ and $\frac{dT_M^*}{d\rho} = (Z^* \frac{dI}{d\rho} + J^* - D^* \frac{dT_M}{d\rho})/X^*$, we can solve for the following equations:

$$\frac{dT_M}{d\rho} = \frac{ZG - (ZH + DE) \frac{dT_M^*}{d\rho}}{\Delta} \tag{2.57}$$

$$\frac{dT_M^*}{d\rho} = \frac{Z^* G + EJ^* + (Z^* N - D^* E) \frac{dT_M}{d\rho}}{\Delta^*} \tag{2.58}$$

These equations are the counterparts to (2.26)-(2.27) under endogenous investment. Now note that (2.58) again contains a free-rider effect, through $-\frac{D^* E}{\Delta^*}$, but also a novel interaction effect working through capital and resource markets, $\frac{Z^* N}{\Delta^*}$. Whereas the sign of the free-rider effect is likely negative again, indicating strategic subsitutes, the sign of the economic interaction effect is ambiguous: both strategic substitutes or complements seem possible. Finally, we obtain the 'general equilibrium' effects of a marginal change in ρ on land policy by substitution:

$$\frac{dT_M}{d\rho} = \frac{ZG\Delta^* - (ZH + DE)(Z^*G + EJ^*)}{\Delta\Delta^* + (Z^*N - ED^*)(ZH + DE)} \tag{2.59}$$

$$\frac{dT_M^*}{d\rho} = \frac{(Z^*G + EJ^*)\Delta + ZG(Z^*N - ED^*)}{\Delta\Delta^* + (Z^*N - ED^*)(ZH + DE)} \tag{2.60}$$

where $\Delta \equiv XE - ZN$ and $\Delta^* \equiv X^*E + Z^*H$. Since $Z \equiv u_{CC}f_Tf_{KK}I + u_Cf_{TK} > 0$, $Z^* \equiv u^*_{CC}f^*_Tf^*_{KK}(\frac{\rho}{1+\rho}K^*_0 + I) - u^*_Cf^*_{TK} \gtrless 0$, $X < 0$, $X^* \lesseqgtr 0$, $D \equiv \eta b_{s*s}s_Ts^*_T \leq 0$, $D^* \equiv \eta^* b_{s*s}s_Ts^*_T \leq 0$, $E \equiv f^*_{KK} + (1+\rho)f_{KK} < 0$, $J^* \equiv u^*_{CC}f^*_T\frac{1}{(1+\rho)^2}f^*_KK^*_0 < 0$, $G \equiv f_K > 0$, $H \equiv f^*_{KT} > 0$ and $N \equiv (1+\rho)f_{KT} > 0$, we find that both derivatives are ambiguous.

Investment Condition for the Cooperative Solution

Assume $b(s,s^*) = s + as^*$, $b^*(s,s^*) = As + s^*$, $Q = \psi L^\alpha(K_0 - I)^\beta(T_M)^\chi$, $Q^* = \psi(L^*)^\alpha(K^*_0 + I)^\beta(T^*_M)^\chi$, $V = C + \eta(s + as^*)$ and $V^* = C^* + \eta^*(As + s^*)$. Then the first-order conditions read:

$$f^*_K = f_K$$

$$f_T = (\eta + \eta^*)s_T$$

$$f^*_T - f^*_{KT}I = (\eta^* + \eta)s^*_T$$

We solve for I from $f^*_K = f_K$, which gives us

$$I = \frac{\left[l^\alpha\left(\frac{T_M}{T^*_M}\right)^\chi\right]^{\frac{1}{\beta}}K_0 - K^*_0}{1 + \left[l^\alpha\left(\frac{T_M}{T^*_M}\right)^\chi\right]^{\frac{1}{\beta}}} = \frac{e^{\frac{1}{\beta}}K_0 - K^*_0}{1 + e^{\frac{1}{\beta}}} \tag{2.61}$$

where $e \equiv l^\alpha\left(\frac{T_M}{T^*_M}\right)^\chi$. Unfortunately, no explicit solution is available when s and s^* are strictly concave. Therefore, we assume $s = \kappa T_H$ and $s = \kappa^* T^*_H$ such that

$$T_M = \left[\kappa(\eta + a\eta^*)\frac{1}{\psi\chi}(L)^{-\alpha}(K_0 - I)^{-\beta}\right]^{\frac{1}{\chi - 1}}$$

$$T^*_M = \left[\kappa^*(A\eta + \eta^*)\frac{1}{\psi\chi}(L^*)^{-\alpha}(K^*_0 + I)^{-\beta}(1 - \beta\frac{I}{K^*_0 + I})^{-1}\right]^{\frac{1}{\chi - 1}}$$

Division:

$$\frac{T_M}{T^*_M} = \left[\frac{\kappa}{\kappa^*}\frac{\eta + a\eta^*}{A\eta + \eta^*}l^{-\alpha}\left(\frac{K_0 - I}{K^*_0 + I}\right)^{-\beta}(1 - \beta\frac{I}{K^*_0 + I})\right]^{\frac{1}{\chi - 1}}$$

Substitution of I from (2.61) into this function gives us:

$$\frac{T_M}{T_M^*} = \left[\frac{\kappa^*}{\kappa} \frac{A\eta + \eta^*}{\eta + a\eta^*} \frac{\frac{\beta + e^{1/\beta}}{e^{1/\beta}} K_0^* + K_0}{K_0^* + K_0} \right]^{\frac{1}{\chi - 1}}$$

Define $z \equiv \frac{T_M^*}{T_M}$ and $g \equiv \frac{\kappa^*}{\kappa} \frac{A\eta+\eta^*}{\eta+a\eta^*} \frac{1}{K_0^*+K_0}$ then z is implicitly defined by:

$$z^{1-\chi} = gK_0 + g(1 + \beta l^{-\frac{\alpha}{\beta}} z^{\frac{\chi}{\beta}}) \tag{2.62}$$

which gives us an interior solution to z. For an interior solution the slope of the left-hand side (in terms of z) should be steeper than the slope of the right-hand side in close proximity of the solution. This conditions reads:

$$\frac{\alpha + \beta}{\chi g(l)^{-\frac{\alpha}{\beta}}} \equiv h > z^{\frac{1-(1+\beta)(\alpha+\beta)}{\beta}}$$

If $1-(1+\beta)(\alpha+\beta) > 0$ then the left-hand side of (2.62) has a steeper (flatter) slope than the right-hand side of (2.62) for all $z > (<) \bar{z}$, where $\bar{z} \equiv h^{\frac{\beta}{1-(1+\beta)(\alpha+\beta)}}$. If $1-(1+\beta)(\alpha+\beta) > 0$ there exists a unique solution z^*, which satisfies $z^* > \bar{z}$.

The Social Optimum

In the social optimum (first-best) the social planner allocates capital and consumption across countries and in each country the available stock of land is allocated between use for production and habitat conservation. The maximization problems reads:

$$\max u(C) + u(C^*) + \eta b(s(T_H), As^*(T_H^*)) + \eta^* b(as(T_H), s^*(T_H^*)) \tag{2.63}$$

subject to

$$C + C^* = Q + Q^* \tag{2.64}$$

$$Q = f(K_0 - I, L, T_M) \quad , \quad Q^* = f(K_0^* + I, L^*, T_M^*) \tag{2.65}$$

$$T = T_H + T_M \quad , \quad T^* = T_H^* + T_M^* \tag{2.66}$$

After substitution of conditions (2.29)-(2.66) into the objective function this becomes an unconstrained maximization problem with respect to four variables $\{C, I, T_M, T_M^*\}$. We do not have to include a restriction on investment,$-K_0^* \leq I \leq K_0$, by assuming $\lim_{I \to K_0} f_K = \infty$ and $\lim_{I \to -K_0^*} f_K^* = \infty$, which assures an interior solution. Maximization yields the following set of first-order conditions:

$$u_C = u_C^* \tag{2.67}$$

$$f_K = f_K^* \tag{2.68}$$

$$u_C f_T = (\eta b_s + a\eta^* b_s^*) s_T \tag{2.69}$$

$$u_C^* f_T^* = (\eta^* b_{s^*}^* + A\eta b_{s^*}) s_T^* \tag{2.70}$$

In the social optimum the marginal utility of consumption is equalized across North and South, see (2.67), and so is the return on capital via equation (2.68). Equations (2.69)-(2.70) are the Samuelson conditions for the optimal provision of biodiversity. To see why, rewrite (2.69) with the use of (2.67) to obtain $\frac{f_T}{s_T} = \frac{\eta b_s}{u_C} + \frac{a\eta^* b_s}{u_C^*}$, where the left-hand side measures the marginal rate of transformation between biodiversity and private consumption and the right-hand side measure the sum of the marginal rate of substitution between biodiversity and consumption in North and South respectively.

In a market economy with free mobility of capital equation (2.68) holds by definition. Equations (2.69)-(2.70) can be implemented if each country installs a Pigouvian tax on land that equals $t_P = \left(\frac{\eta b_s}{u_C} + \frac{a\eta^* b_s}{u_C^*}\right) s_T$ and $t_P^* = \left(\frac{A\eta b_{s^*}}{u_C} + \frac{\eta^* b_{s^*}}{u_C^*}\right) s_T^*$ in North and South respectively. In addition, with the use of a lump-sum transfer from North to South (or vice versa) one can implement (2.67).

Chapter 3

The Pollution Haven Hypothesis: a Dynamic Perspective [1]

> "*Today, a couple of decades into their industrial revolutions, China has 1.3 billion people and India has 1.1 billion. What both countries pursue is growth on a scale that is more than 200 times larger than what the UK and the US managed during their industrial revolutions. Well-informed observers of Chindia argue that Chindia will avoid.. (environmental) disasters by learning to price ... scarce resources (especially water) appropriately. Chindia will not have a century or more to figure out how to make growth environmentally sustainable—a process still far from complete in the UK and the US. They have less than a decade".* Willem Buiter (2007),'The Browning of Chindia'

3.1 Introduction

The 'East Asian Miracle' is a topic in recent economic history that has received considerable attention from the economics profession. It tells an interesting story of a collection of export-oriented economies that have experieced high growth rates for more than three decades. It fits in a larger series of events in global economic development and encompasses various post-war economic trends. Among these trends that are confirmed by the empirical data are the conditional convergence of open economies, the increase in the volume of world trade and, in a seemingly whole other sphere of interest, the steady degradation of the global environment according to various ecological indicators. Conditional convergence explains how poor countries that are open to trade grow faster than their high-income partners. This process has been accompanied by increases in the volume of trade between high-income countries and the newcomers. It has, however, not yet been made clear how the various polluting industries, one of the root causes of global environmental degradation, are distributed across trading partners over time. The fact that there has not been much inquiry into the environmental repercussions of economic growth in open economies is understandable from an empirical point of view: the growth experience that we have referred to is that

[1] This chapter has also appeared as Bogmans & Withagen (2010).

of a number of relatively small economies. Their joint impact on world aggregates, be it economic or environmental, is very modest.

None of this holds true whatsoever for the growth process of 'Chindia'; together, China and India hold more than 1/3th of the world's population. China's rise to its role as the 'manufacturer of the world', as it is often denoted in the popular press, is unprecedented in terms of both speed and scale. As with the East-Asian miracle, many argue that China's process of development is characterized by trade-led growth with growth rates that exceed those of its most important trading partners, the European Union and the United States, by several percentage points.

Our analysis is a first attempt to capture these recent facts in economic history and, more generally, to provide for a dynamic perspective of the pollution haven hypothesis (for a clear definition we refer the reader to the next paragraph). The framework that we propose could be a first step towards a more comprehensive theory of pollution havens; one that pays particular attention to i) economic dynamics and ii) the increasing importance of international trade in the world economy, not only in final goods but also in intermediate goods, ideas, factors of production etc. This process of global integration is, in contrast to what some might think (see, for example, Friedman (2005)), not completed. From a theoretical point of view this implies that the world is still far from the hypothetical 'integrated world equilibrium' that trade theorists are so fond of (Dixit and Norman, 1981;Ventura, 2005). Therefore, our approach seems relevant.

This chapter incorporates optimal saving and investment behavior into a $2 \times 2 \times 2$ Heckscher-Ohlin framework with environmental damage from pollution. With the dynamic trade model that is obtained we derive the necessary conditions, related to demand side and supply side parameters, under which a country can become a net exporter of the dirty good, i.e. a pollution haven. We do this in a setting where (i) both sectors of production make use of a polluting factor of production, (ii) the pollution that is generated by production is local in nature and (iii) environmental policy is endogenous. Our analysis adds to the literature by emphasizing the deeper determinants of specialization patterns and pollution havens, especially the subjective time discount rate. In the steady state, the relatively impatient country will produce the dirty good. While some of our results relate to previous models in the literature, other results are new and provide for avenues in future research. We also sketch how the model can be extended to analyze some positive and normative questions related to income convergence, convergence of industry emission intensities and trade.

This chapter is organized as follows. Section 2 provides an overview of the literature. Section 3 outlines our dynamic trade model. In section 4 we discuss the properties of the steady state in autarky. In section 5 we move to a situation with international trade. It is shown that even the slightest difference in the rate of time preference across countries will cause at least one country to specialize completely in the steady state. We derive necessary conditions for the various types of pollution havens and show some examples. Section 6 concludes.

3.2 Overview of the literature

Our analysis contributes to several strands of the literature. First, there is a by now voluminous literature on the relationship between international trade and the environment. The main question here is whether trade, through its effects on technology, the scale and the composition of economic activity, is beneficial for the environment. Seminal contributions in this field are by Grossman and Krueger (1994), Copeland and Taylor (1994, 2003) and Antweiler et al. (2000). Copeland and Taylor (1994) analyze the relationship between trade and the environment in a North-South Ricardian trade model with a continuum of goods, following Dornbusch et al. (1977). They assume that North and South differ in terms of technology (or human capital). As a result North has a higher level of income. Under endogenous environmental policy the income difference implies that the North sets a more stringent environmental policy. This mechanism creates an income-induced comparative advantage for the North in the clean good. Due to its lower level of income and less stringent environmental policy the South becomes a net exporter of dirty goods. Thus, their model is an elaborate example of the pollution haven hypothesis (PHH); low-income, labor abundant countries will specialize in the production of dirty goods. In Copeland and Taylor (2003) this theory is modified by incorporating the factor endowment hypothesis which states the exact opposite of the PHH: high-income and capital-abundant countries will become a net exporter of dirty goods. It is now recognized that, at least in theory, these two countervailing forces that are exerted through a country's capital-labor ratio jointly determine the specialization pattern in open economies.

A second strand of the literature that is important for our work is concerned with capital accumulation in open economies. Since the interest rate in open economies is determined by the terms of trade, the process of growth through capital accumulation is distinct from that in closed economies. Seminal publications in the field of dynamic H-O models are by Oniki and Uzawa (1965) and Stiglitz (1970). These authors assume exogenous savings rates as in Solow (1956). Cross-country differences in savings rates imply that, even though the long-term balanced growth rate is exogenous and equal to the rate of technological progress, the steady state capital-labor ratio will differ between countries. Thus, cross-country production patterns will be distinct even in the steady state. More recently Baxter (1992) and Ono and Shibata (2006), among others, have incorporated intertemporal optimization behavior to endogenize saving rates. Classical Ricardian properties such as perfect specialization reemerge in this context since the steady state interest rate, and therefore the capital-labor ratio, are fixed by the rate of time preference. This feature sets these models apart from their predecessors with exogenous saving rates. Dynamic H-O models are also being used for a variety of more specialized topics, such as endogenous growth with both human capital and physical capital accumulation (Bond et al., 2003), fiscal policy and global welfare analysis (Ono and Shibata, 2005), trade, growth and convergence (Ventura, 1997, Acemoglu and Ventura, 2002) and, finally, status-seeking and catching-up (Hu and Shimomura, 2007). Thus, the dynamic H-O model has become a very important tool for studying the short-run and long-run determinants of comparative advantage in relation to other important questions in dynamic economic theory.

Here we apply dynamic H-O theory to analyze the relationship between international trade and the environment with endogenous environmental policy. Our analysis is somewhat related to a recent paper by Umanskaya and Barbier (2008). They introduce the concept of a true pollution haven: a situation in which a country specializes completely in the production of dirty goods. Remember that the standard definition of a pollution haven was less restrictive: 'A country that, because of its weak or poorly enforced environmental regulations, attracts industries that pollute the environment' (Deardoff, 2001). This definition, however, has nothing to say on the overall production pattern of a particular country. Umanskaya and Barbier (2008) use a static two-country trade model to show that true pollution havens can be obtained as the outcome of differences in factor endowments and income generated differences in environmental policy. Their result is caused by the assumption of sufficiently large differences in factor endowments such that factor price equalization is not obtained. Then the implications of the model are in line with Ricardian trade theory: at least one of the two countries becomes completely specialized. In our model we derive a dynamic version of this proposition that is even sharper: an infinitely small difference in the subjective discount rate or technology assures that at least one country becomes a true pollution haven in the steady state.

3.3 A Ramsey-Heckscher-Ohlin model with pollution

We formulate a dynamic trade model in continuous time. There are two countries, Home and Foreign. Foreign variables are denoted with an asterisk (*). Two goods, a relatively clean good (X) and a relatively dirty good (Y), are produced using two factors of production, a clean factor and a dirty factor. The technology has constant returns to scale. We assume that the production of the clean (dirty) good is relatively intensive in the clean (dirty) factor of production. These factors can be interpreted as respectively physical capital (K) and emission permits (Z). The initial capital stock is given: $K_0 > 0$. The clean good is the numeraire and serves a dual function: it is suitable for both investment (I) and consumption (C_x). The dirty good can only be used for consumption (C_y). Such a distinction between the two goods is common in the literature on dynamic H-O models. On the consumption side each household determines its composition of consumption (C) and the path of private assets (A). Households take the level of environmental quality as given. The level of environmental quality is proportional to the level of flow pollution. Pollution is proportional to the use of the dirty input. The government sets the price of emissions (ϑ) to balance the benefits and costs of flow pollution. Pollution damage is local only. In the following we describe the home economy. The foreign economy is similar.

3.3.1 Consumption

There is an infinitely lived agent who cares only about his or her consumption and environmental quality. Flow pollution is assumed to be harmful for the consumer. Lifetime welfare $\Lambda(t)$ of the agent at time t is given by:

$$\Lambda \equiv \int_0^\infty [U(C_x(s), C_y(s)) - D(Z(s))]e^{-\rho s} ds$$

with U the utility of consumption, D the damage function and ρ the rate of pure time preference. The utility function has the usual properties, including homotheticity. The damage function is increasing and strictly convex in Z, $D'(Z) > 0, D''(Z) > 0$ for $Z > 0$. Also, $D(0) = 0$. The representative agent maximizes lifetime welfare subject to the lifetime budget constraint:

$$\int_0^\infty \exp[-\int_0^s r(\tau)d\tau][C_x(s) + p(s)C_y(s)]ds \leq A_0 + T_0$$

where A_0 is the initial amount of assets owned by local residents, r is the gross interest rate, p is the price of the dirty commodity and

$$T_0 \equiv \int_0^\infty \exp[-\int_0^s r(\tau)d\tau]T(s)ds$$

is the lifetime value of discounted government transfers. Transfers $T(t)$ are equal to the government revenues from emission taxation, $T(t) = \vartheta Z(t)$. So, the government has a balanced budget in each period. We also have the household per-period budget identity:

$$\dot{A}(t) = r(t)A(t) + T(t) - C_x(t) - p(t)C_y(t)$$

The change in assets holdings by domestic residents equals the difference in income and expenditures, where income consists of the sum of interest on asset holdings and government transfers. We can retrieve the lifetime budget constraint by integrating the budget identity and applying the appropriate transversality condition, $\lim_{\tau\to\infty} A(\tau)\exp[-\int_t^\tau r(s)ds] = 0$[2]. This completes the description of the demand side of the model.

3.3.2 Production

Firms in each sector $j = x, y$ maximize the present value of current and future profits by buying permits Z_j from the government and renting capital K_j from the investment sector. As mentioned before the technology of production in each sector is subject to constant returns to scale and firms take prices as given. Discounted profits are:

$$\Pi_x(t) = \int_t^\infty [F(K_x(s), Z_x(s)) - r(s)K_x(s) - \vartheta(s)Z_x(s)]e^{-\int_t^s r(\tau)d\tau}ds$$

$$\Pi_y(t) = \int_t^\infty [p(s)G(K_y(s), Z_y(s)) - r(s)K_y(s) - \vartheta(s)Z_y(s)]e^{-\int_t^s r(\tau)d\tau}ds$$

F (G) is the constant returns to scale production function of the clean (dirty) commodity with diminishing returns to each factor of production. Two remarks are in order with respect to the production

[2] In the next section it will turn out that, since physical capital is the only asset in this economy, the amount of asset holdings by domestic residents equals the stock of physical capital.

technology. Many authors have emphasized that pollution can be equivalently treated as an output or input to production. For example, Z can be seen as the use of environmental services as a firm disposes its waste into the environment. Or, Z can be taken as the number of permits that a firm has to buy in order to be allowed to pollute (Copeland and Taylor, 2003). To see this, consider a firm that employs capital as the only factor of production and jointly produces a commodity X and emissions Z. The firm has access to an abatement technology that allows it to reduce the pollution intensity of production $e_x(\theta)$:

$$\begin{aligned} X &= (1-\theta)F(K_x) \\ Z_x &= e_x(\theta)F(K_x) \end{aligned}$$

with $e_x(\theta) = (1-\theta)^{\frac{1}{1-\beta}}$. Then we can rewrite the firm's production technology as a production function with capital and emissions as inputs:

$$X = F(K_x)^{\beta} Z_x^{1-\beta} \quad , \quad 0 < \beta < 1$$

If $F(K_x)$ takes the form of a simple AK production function the production function effectively turns into a constant returns to scale production function.

From here on we continue with the input-representation of emissions. Either way, there exists a price (tax) ϑ for the use of this input (output). Homogeneity of the production functions allows us to work with output-pollution and capital-pollution ratios. The intensive production functions are denoted by f and g. The first-order conditions for an interior solution can then be rewritten as

$$r(t) = f'(k_x(t)) = p(t)g'(k_y(t)) \tag{3.1}$$

$$\vartheta(t) = f(k_x(t)) - f'(k_x(t))k_x(t) = p(t)[g(k_y(t)) - g'(k_y(t))k_y(t)] \tag{3.2}$$

where $k_j \equiv \frac{K_j}{Z_j}$ denotes the capital-permit ratio in sector j. We make the following assumption.

(A1). *The production function* $f : \mathbb{R}_+ \to \mathbb{R}_+$ *has the usual neo-classical properties,* $f(0) = 0$, $f'(k) > 0$, $f''(k) < 0$ *for all* $k > 0$. *In addition* $\lim_{k\to 0} f'(k) = \infty$, $\lim_{k\to\infty} f'(k) = 0$. *The function* g *has the same properties. Moreover* f *is more capital-intensive than* g, *that is,* $f(k) > g(k)$ *for any* $k > 0$.

In the sequel we will amply make use of the concept of the factor price frontier. The factor price frontier of the production function F is the locus of points (r, ϑ) for which maximal profits are zero. It is denoted by fpf(F). The factor price frontier of G, given the price p, sometimes conveniently phrased as the factor price frontier of pG, is the set of factor prices (r, ϑ) for which maximal profits are zero, at the price p. It is denoted by fpf(pG). Both loci are decreasing in (r, ϑ)-space, and due to our assumption (A1), fpf(F) is less steep than fpf(pG). See Figure 3.1 below.

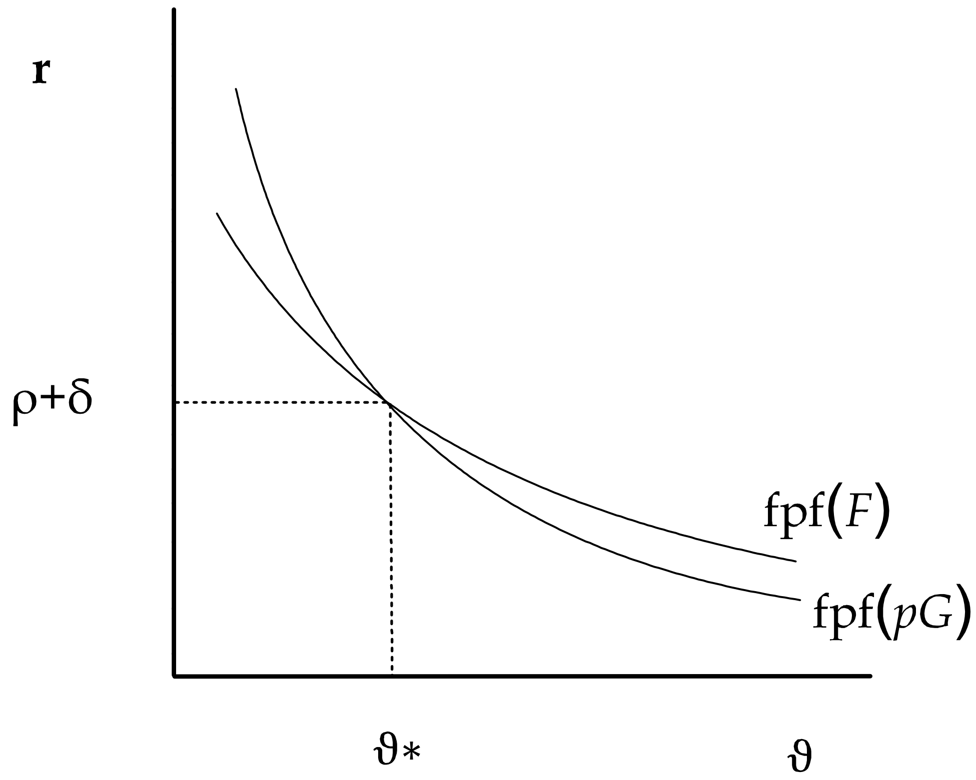

Figure 3.1: Factor Price Frontiers

3.3.3 Equilibrium

Market equilibrium for permits and for capital requires

$$Z(t) = Z_x(t) + Z_y(t) \tag{3.3}$$

$$K(t) = K_x(t) + K_y(t) \tag{3.4}$$

In autarky equilibrium on the goods market prevails if

$$\dot{K}(t) = F(K_x(t), Z_x(t)) - C_x(t) - \delta K(t),\ K(0) = K_0 \tag{3.5}$$

$$C_y(t) = G(K_y(t), Z_y(t)) \tag{3.6}$$

Since we abstract from trade in permits we still have (3.3) for each country. Since capital is not mobile either, trade is balanced, and net exports equal net imports for both countries. This implies that total income equals total expenditures:

$$F(K_x(t), Z_x(t)) + p(t)G(K_y(t), Z_y(t)) = C_x(t) + p(t)C_y(t) + \delta K(t) + \dot{K}(t) \tag{3.7}$$

$$F^*(K_x^*(t), Z_x^*(t)) + p(t)G^*(K_y^*(t), Z_y^*(t)) = C_x^*(t) + p(t)C_y^*(t) + \delta K^*(t) + \dot{K}^*(t) \tag{3.8}$$

and

$$C_y(t) + C_y^*(t) = G(K_y(t), Z_y(t)) + G^*(K_y^*(t), Z_y^*(t)) \tag{3.9}$$

Regarding environmental policy we assume that the government sets the emission tax equal to marginal damage of pollution. The pollution tax is Pigouvian.

3.4 Autarky

Since the government internalizes the only external effect a general equilibrium is Pareto efficient. We can therefore characterize the equilibrium by considering the program that maximizes social welfare. So, we look at

$$\max \int_0^\infty [U(C_x(s), C_y(s)) - D(Z(s))]e^{-\rho s} ds$$

subject to (3.3), (3.4), (3.5) and (3.6). The present-value Hamiltonian reads

$$\begin{aligned} H \quad = \quad & e^{-\rho t}[U(C_x, C_y) - D(Z)] + \tilde{\lambda}[F(K_x, Z_x) - C_x - \delta K] + \tilde{\mu}[G(K_y, Z_y) - C_y] \\ & + \tilde{r}[K - K_x - K_y] + \tilde{\vartheta}[Z - Z_x - Z_y] \end{aligned}$$

with $\tilde{\lambda}$ the co-state variable corresponding with capital, and $\tilde{\mu}$, $\tilde{r}$ and $\tilde{\vartheta}$ Lagrangian multipliers. There exists a solution to this problem. Given our convexity assumptions it is unique. Moreover, the solution is interior. The necessary conditions read

$$\frac{\partial H}{\partial C_x} = 0: \; U_x(C_x(t), C_y(t)) = \lambda(t) \tag{3.10}$$

$$\frac{\partial H}{\partial C_y} = 0: \; U_y(C_x(t), C_y(t)) = p(t)\lambda(t) \tag{3.11}$$

$$\frac{\partial H}{\partial K_x} = 0: \; F_k(K_x(t), Z_x(t)) = r(t) \tag{3.12}$$

$$\frac{\partial H}{\partial K_y} = 0: \; p(t)G_k(K_y(t), Z_y(t)) = r(t) \tag{3.13}$$

$$\frac{\partial H}{\partial Z_x} = 0: \ F_z(K_x(t), Z_x(t)) = \vartheta(t) \tag{3.14}$$

$$\frac{\partial H}{\partial Z_y} = 0: p(t)G_z(K_y(t), Z_y(t)) = \vartheta(t) \tag{3.15}$$

$$\frac{\partial H}{\partial K} = -\dot{\tilde{\lambda}}: \ \dot{\lambda}(t)/\lambda(t) = \rho + \delta - r(t) \tag{3.16}$$

$$\frac{\partial H}{\partial Z} = 0: \ D'(Z(t)) = \vartheta(t)\lambda(t) \tag{3.17}$$

where $\lambda(t) = e^{\rho t}\tilde{\lambda}(t), \ p(t) = \tilde{\mu}(t)/\tilde{\lambda}(t), \ \vartheta(t) = \tilde{\vartheta}(t)/\tilde{\lambda}(t), r(t) = \tilde{r}(t)/\tilde{\lambda}(t)$. The prices $p(t)$, $r(t)$ and $\vartheta(t)$ can and will be interpreted as market prices in the sequel.

For the time being we are mainly interested in the steady state, characterized by a constant stock of capital as well as a constant shadow price λ. In the sequel we will denote steady state values by variables without the time argument. Let us define $\omega = k_x$ and $\psi = k_y$, the steady state values of the capital-permit ratios. Then by (3.12)-(3.16) we have

$$r = \rho + \delta = f'(\omega) = pg'(\psi) \tag{3.18}$$

$$\vartheta = f(\omega) - f'(\omega)\omega = p[g(\psi) - g'(\psi)\psi] \tag{3.19}$$

Therefore, r, ϑ, ψ, ω and p are uniquely determined. From (3.3) and (3.4) we get

$$z_x \equiv \frac{Z_x}{Z} = \frac{k - \psi}{\omega - \psi} = z_x(k) \tag{3.20}$$

$$z_y \equiv \frac{Z_y}{Z} = \frac{\omega - k}{\omega - \psi} = z_y(k) \tag{3.21}$$

with $k = K/Z$. Moreover, from (3.5) and (3.6) we have

$$\frac{C_x}{C_y} = \frac{f(\omega)z_x - \delta k}{g(\psi)(1 - z_x)} \tag{3.22}$$

Since the utility function is homothetic, relative consumption is a function of the relative price only, $C_x/C_y = h(p)$. Using this and through (3.17) $D'(Z) = \vartheta(p)U_x(h(p))$ we find the steady state for pollution Z. Substitution of $h(p)$ into (3.22) gives us the solution for the autarky aggregate capital-permit ratio :

$$k = \frac{f(\omega)\psi + h(p)g(\psi)\omega}{f(\omega) + h(p)g(\psi) - \delta(\omega - \psi)} \tag{3.23}$$

Finally, Z_x follows from z_x and Z.

Note that capital is monotonically increasing or monotonically decreasing, since it is the only state variable and the solution is unique. Moreover, capital approaches a finite steady state $K = kZ$. We summarize our findings in the following proposition.

Proposition 1. *Consider the competitive equilibrium of the Ramsey-Hecksher-Ohlin model with pollution. In autarky there exists a unique steady state. The system is globally asymptotically stable.*

Now that we have examined the basic properties of the model under autarky, we turn our attention to a setting with international trade.

3.5 International trade

In this section we allow for international trade in final goods. Trade is balanced in every period. The problem facing an open economy reads

$$\max \int_0^\infty [U(C_x(s), C_y(s)) - D(Z(s))]e^{-\rho s} ds$$

subject to (3.3), (3.4) and

$$\dot{K}(t) = F(K_x(t), Z_x(t)) - C_x(t) - \delta K(t) - p(t)X_y(t) \tag{3.24}$$

$$C_y(t) + X_y(t) = G(K_y(t), Z_y(t)) \tag{3.25}$$

where X_y is the net export of the clean commodity. The present-value Hamiltonian reads

$$\begin{aligned} H \quad = \quad & e^{-\rho t}[U(C_x, C_y) - D(Z)] \\ & +\tilde{\lambda}[F(K_x, Z_x) - C_x - p(t)X_y - \delta K] \\ & +\tilde{\mu}[G(K_y, Z_y) - C_y - X_y] \\ & +\tilde{r}[K - K_x - K_y] \\ & +\tilde{\vartheta}[Z - Z_x - Z_y] \end{aligned}$$

For consumption the solution is interior. Hence

$$\frac{\partial H}{\partial C_x} = 0 : \; U_x(C_x(t), C_y(t)) = \lambda(t)$$

$$\frac{\partial H}{\partial C_y} = 0 : U_y(C_x(t), C_y(t)) = p(t)\lambda(t)$$

$$\frac{\partial H}{\partial X_y} = 0 : U_y(C_x(t), C_y(t)) = p(t)\lambda(t)$$

Furthermore, at each instant of time, the Hamiltonian is maximized with respect to the inputs of each production factor

$$\max \; F(K_x, Z_x) - r(t)K_x - \vartheta(t)Z_x$$

$$\max\ p(t)G(K_y, Z_y) - r(t)K_y - \vartheta(t)Z_y$$

Finally

$$\frac{\partial H}{\partial K} = -\dot{\tilde{\lambda}}:\ \dot{\lambda}(t) = (\delta + \rho - r(t))\lambda(t)$$

$$\frac{\partial H}{\partial Z} = 0:\ D'(Z(t))/\lambda(t) = \vartheta(t)$$

Here $\lambda(t) = e^{\rho t}\tilde{\lambda}(t),\ p(t) = \tilde{\mu}(t)/\tilde{\lambda}(t),\ \vartheta(t) = \tilde{\vartheta}(t)/\tilde{\lambda}(t),\ \vartheta^*(t) = \tilde{\vartheta}^*(t)/\tilde{\lambda}(t),\ r(t) = \tilde{r}(t)/\tilde{\lambda}(t)$. Again we interpret $r(t)$ and $\vartheta(t)$ as the return on capital and the price of emissions, which is warranted in a first best world. In the next section we will examine the various types of long-run equilibria in this model.

3.5.1 Identical countries and long-run specialization patterns

In this section we assume that countries are completely identical in every aspect except (maybe) in terms of their initial capital endowments. Since there are two countries and two commodities there are seven candidates for an equilibrium. Of these seven types of equilibria only four are distinct because there are three symmetric pairs. We identify the following equilibrium configurations:

Case 1) Imperfect specialization, denoted by (FGF^*G^*)
Case 2) Perfect specialization in the clean good by one country, denoted by (FGF^*) or (FF^*G^*)
Case 3) Perfect specialization in the dirty good by one country, denoted by (GF^*G^*) or (FGG^*)
Case 4) Perfect specialization by both countries, denoted by (GF^*) or (FG^*)

We can make general statements with respect to steady-state prices, capital-permit ratios and some quantities regardless of the specific specialization pattern. We summarize this in the following proposition.

Proposition 2 *A steady state is characterized by*
(i) factor price equalization (FPE).
(ii) equal flows of pollution in each country, $Z = Z^*$.
(iii) identical quantities of world capital and world pollution across steady states.

Proof. (i) In a steady we have $r = r^* = \rho + \delta$. Suppose $F > 0$. Then ω follows through $f'(\omega) = \rho + \delta$. The permit price follows from $\vartheta = f(\omega) - f'(\omega)\omega$. It must be the case that $\vartheta^* \geq \vartheta$. Now suppose that $\vartheta^* > \vartheta$. This implies $F^* = 0$ because otherwise profits would be negative. Hence $G^* > 0$. From this and the assumption that $\vartheta^* > \vartheta$ it follows that home could make unbounded profits by producing Y, since the home factor prices are lower than the foreign factor prices. This is a contradication and hence $\vartheta^* = \vartheta$. The same reasoning applies if $F^* > 0$. This completes the first part of the proof.

(ii) As in the case of autarky the steady state value of ψ and the steady state price p are obtained through the set of equations $pg'(\psi) = \rho + \delta$ and $p[g(\psi) - g'(\psi)\psi] = \vartheta = \vartheta^*$. Since preferences are homothetic relative consumption is a function of the relative price only, $C_x/C_y = C_x^*/C_y^* = h(p)$. Then $\lambda = \lambda^*$ follows from $U_x(C_x/C_y) = U_x(h(p)) = \lambda$. Subsequently $Z = Z^*$ follows from $D'(Z) = \lambda\vartheta = D'(Z^*) = \lambda^*\vartheta^*$. This completes the second part of the proof.

(iii) Denote pollution derived in the previous part of the proof by Z. We have, allowing for the possibility that a sector is not active,

$$\begin{aligned} K &= \frac{K_x}{Z_x}Z_x + \frac{K_y}{Z_y}Z_y = \frac{K_x}{Z_x}Z_x + \frac{K_y}{Z_y}(Z - Z_x) \\ &= (\omega - \psi)Z_x + \psi Z \end{aligned}$$

Similarly

$$K^* = (\omega - \psi)Z_x^* + \psi Z$$

So,

$$K + K^* = (\omega - \psi)(Z_x + Z_x^*) + 2\psi Z$$

Moreover, from (3.7), (3.8) and (3.9)

$$C_y + C_y^* = G + G^*$$

$$C_x + pC_y = F + pG - \delta K$$

$$C_x^* + pC_y^* = F^* + pG^* - \delta K^*$$

From utility maximization we have

$$C_x = h(p)C_y$$

$$C_x^* = h(p)C_y^*$$

Hence, after straightforward calculations, and with some abuse of notation

$$\delta(K + K^*) = (Z_x + Z_x^*)(f(\omega) + h(p)g(\psi)) - 2h(p)Zg(\psi)$$

Therefore, we have two linear equations in the two unknowns $K + K^*$ and $Z_x + Z_x^*$. Hence world capital in the steady state follows:

$$K_w = K + K^* = \frac{f(\omega)\psi + h(\bar{p})g(\psi)\omega}{f(\omega) + h(p)g(\psi) - \delta(\omega - \psi)}2Z \tag{3.26}$$

This completes the final part of the proof.

A steady state with imperfect specialization is any pair (K, K^*) such that $K + K^* = K_w$ and both countries produce both goods. These steady states, as do the others, exhibit a very simple structure:

levels of world income, production, pollution and consumption are equal across steady states. This is uncommon for models with flexible factors of production. The primary reason for this is that the supply of pollution is independent of national income. With Cobb-Douglas utility, the indirect utility function is linear in income. In that case the Samuelson rule states that the marginal rate of substitution between consumption and environmental pollution, $D'(Z)/U_x(h(p)) = \vartheta(p)$, is independent of income. As a result, the supply of pollution is only subject to substitution (price) effects[3]. Furthermore, all steady states are characterized by factor price equalization: interest rates and permit prices are equalized across countries. This is a distinctive feature of our dynamic model. To see why, consider the standard static $2 \times 2 \times 2$ Heckscher-Ohlin framework with labor and capital as factors of production. In this setting FPE and imperfect specialization are two sides of the same coin: if endowments of both countries lie within the so-called FPE set both countries will produce both goods (see Dixit and Norman, 1980). Here, on the other hand, we find that factor price equalization is consistent with specialization in the very long run (cases 2 and 3). That would imply that true pollution havens might emerge even outside your typical North-South setting (Copeland and Taylor, 1994). Before presenting a diagram that shows all the different steady states in (K, K^*)-space, we note that there is another property of the model that is worth mentioning:

Corollary *The Ramsey-Hecksher-Ohlin model features a scale effect. Under international trade with two countries all world quantities related to production, pollution and capital are exactly twice as large under autarky.*

This observation follows directly from the previous proposition. On the one hand and in line with many endogenous growth models, we have two variable factors of production. On the other hand, growth of emissions is limited by the stringency of environmental policy, which reflects a strictly convex damage function and an indirect utility function that is linear in income. Interestingly, this leads to both neoclassical growth properties and endogenous growth properties. From the AK-model it inherits the scale effect.[4] In the long-run, however, the model is characterized by zero growth which reminds us of the Ramsey model.

We now derive the conditions under which each of the steady states prevails. Consider the set of equations, derived in proposition 2 and repeated here for convenience

$$K + K^* = (\omega - \psi)(Z_x + Z_x^*) + 2\psi Z \tag{3.27}$$

$$\delta(K + K^*) = (Z_x + Z_x^*)(f(\omega) + h(p)g(\psi)) - 2h(p)Zg(\psi) \tag{3.28}$$

In the first equation we have $K + K^* = 2\omega Z$ for $Z_x + Z_x^* = 2Z$ (note that Z is fixed, as derived in proposition 2). A necessary and sufficient condition for having a solution with $K + K^* > 0$ and $Z_x + Z_x^* < 2Z$ is that $f(\omega) > \delta\omega$. Of course, if one is interested in a steady state this is a natural

[3]A dynamic H-O model with capital and labor as factors of production (and with fixed labor supply in each country) would exhibit a similar steady state with determinate production levels but a-priori unknown trade patterns.

[4]Remember that in section three we discussed the equivalence of our model with a two-sector AK-model.

assumption to make. It requires that positive long run consumption is feasible. We next consider the possible steady states.

Case 1. (FGF^*G^*). Suppose the steady state is interior. Then of course (3.27) and (3.28) have to hold. Moreover,

$$K = (\omega - \psi)Z_x + \psi Z$$

$$K^* = (\omega - \psi)Z_x^* + \psi Z$$

Hence, in order to have an interior solution for pollution we need $\psi Z < K < \omega Z$ and $\psi Z < K^* < \omega Z$.

Case 2. (FGF^*) and (FF^*G^*). Suppose the steady state has $F > 0, G > 0, F^* > 0, G^* = 0$. Then $K^* = \omega Z$ and $Z_x^* = Z$. So, the two equations (3.27) and (3.28) now become

$$K = (\omega - \psi)Z_x + \psi Z$$

$$\delta K = Z_x(f(\omega) + h(p)g(\psi)) + Z(f(\omega) - h(p)g(\psi) - \delta\omega)$$

We have $\omega - \psi > 0$ by assumption and $f(\omega) + h(p)g(\psi) > 0$. So, both lines are upward sloping. Moreover, $f(\omega) + h(p)g(\psi) > \delta(\omega - \psi)$, implying that the latter line is steeper than the former. For $Z_x = Z$ the former yields $K = \omega Z$ and the latter gives $K > \omega Z$. So, to have an interior solution, with $0 < Z_x < Z$ we need $f(\omega) - h(p)g(\psi) < (\omega + \psi)\delta$. Therefore, if $K^* = \omega Z$ and if K solves these two equations, the steady state is given by $F > 0$, $G > 0$, $F^* > 0$, $G^* = 0$. Obviously, if $K = \omega Z$ and if K solves the two equations, the steady state is given by $F > 0$, $G = 0$, $F^* > 0$, $G^* > 0$.

Case 3. (FGG^*) and (GF^*G^*). Next, suppose that there is a steady state with $F > 0$, $G > 0$, $F^* = 0$, $G^* > 0$. Then $K^* = \psi Z$ and $Z_x^* = 0$. So, the two equations (3.27) and (3.28) become

$$K = (\omega - \psi)Z_x + \psi Z$$

$$\delta K = Z_x(f(\omega) + h(p)g(\psi)) - Z(2h(p)g(\psi) + \delta\psi)$$

Again, both lines are upward sloping. Moreover, $f(\omega) + h(p)g(\psi) > \delta(\omega - \psi)$, implying that the latter line is steeper than the former. For $Z_x = Z$ the former yields $K = \omega Z$ and the latter gives $K > \omega Z$ if and only if $f(\omega) - h(p)g(\psi) > (\omega + \psi)\delta$. If that condition is satisfied we also have $0 < Z_x < Z$. Therefore, if $K^* = \omega Z$ and if K solves these two equations, the steady state is given by $F > 0$, $G > 0$, $F^* = 0$, $G^* > 0$. Obviously, if $K = \psi Z$ and if K solves these two equations, the steady state is given by $F = 0$, $G > 0$, $F^* > 0$, $G^* > 0$.

Case 4. (FG^*) and (GF^*). Finally, suppose that there is a steady state with $F > 0$, $G = 0$, $F^* = 0$, $G^* > 0$. Then $K = \omega Z$ and $K^* = \psi Z$. So, $K + K^* = \omega Z + \psi Z$. However, the probability that these values satisfy equations (3.27) and (3.28) is zero. This also holds for the case (GF^*). Hence, we will almost never observe a steady state with perfect specialization.

The graph below sketches the steady state equilibrium values of capital. Here the numbers correspond with the constellations as defined at the outset of this section. It is important to note that we have depicted

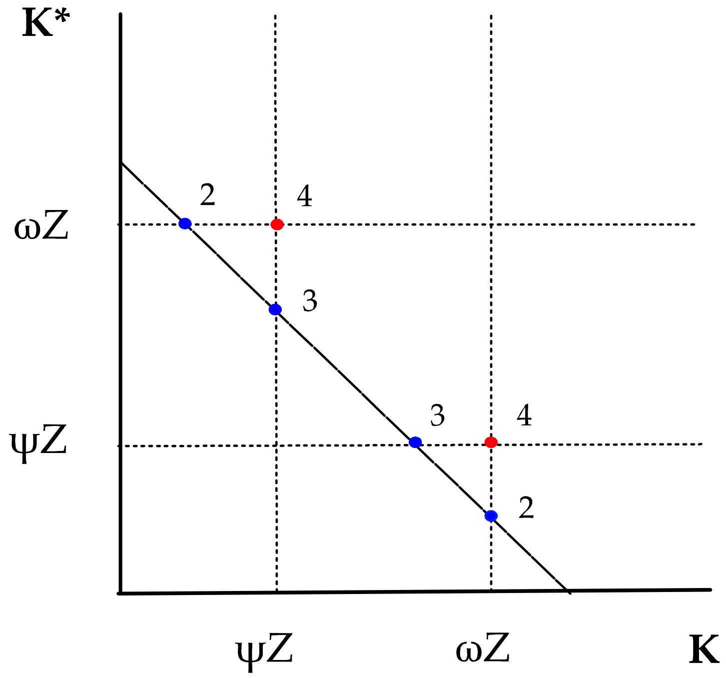

Figure 3.2: Cone of Specialization

only equilibrium candidates: the conditions derived above have to be satisfied in addition to the location of the capital stocks. For example, suppose that all the conditions for a type 2 equilibrium are met. Then, as will become clear from the next proposition as well, it follows that all the other equilibria in the figure are characterized by world excess supply of one of the two commodities.

The identification of the steady state values of capital corresponding with the equilibrium constellations does not yet answer the question of the stability of these values. Nor does it solve the way in which convergence, if any, takes place. This is subject to further research.

A final observation that can be made from the previous conditions is that steady states of type 2, 3 and 4 are isolated points.

Define:

$$\Psi \equiv f(\omega) - h(\bar{p})g(\psi) - \delta(\omega + \psi)$$

and K_w as the solution of (3.27) and (3.28). Then we can summarize the previous results in the following proposition:

Proposition 3. There exists a steady state if and only if $f(\omega) > \delta\omega$. Moreover,

1) $FGF^*G^* \Leftrightarrow K + K^* = K_w$ and $\psi Z < (K, K^*) < \omega Z$
2) $FGF^* \Leftrightarrow \Psi < 0, K + K^* = K_w$ and $K^* = \omega Z$
3) $FGG^* \Leftrightarrow \Psi > 0, K + K^* = K_w$ and $K^* = \psi Z$
4) $FG^* \Leftrightarrow \Psi = 0$ and $K + K^* = K_w$ and $K^* = \psi Z$ and $K = \omega Z$

From figure 2 we can drive several other interesting results. Consider the case of the foreign country specializing in the clean good: $F^* > 0$, $G^* = 0$. We then are in the upper left hand corner of figure 2. This equilibrium requires a foreign capital stock that is higher than in any other equilibrium. The explanation is intuitive. For foreign to specialize completely in the clean good it has to have a relatively large aggregate capital-permit ratio when compared with imperfect specialization. Since the pollution rates do not differ across regimes this directly implies that the capital stock must be higher.

Finally, steady state welfare in the country that is perfectly specialized in the clean good is strictly larger than under imperfect specialization. Since pollution damages are equal in all allocations a sufficient condition is that income under complete specialization is higher than under imperfect specialization. Income reads $I = rK + \vartheta Z$. Since the rate of return, the permit price and pollution do not differ across regimes the only parameter that counts is the stock of capital. That welfare is higher under complete specialization than under imperfect specialization is a typical result in Ricardian trade theory. Here it is often acknowledged that the largest gains from trade are for the small country that specializes completely. 'Small' should be interpreted as having a relatively small steady state capital endowment.

3.5.2 Is a patient nation a dirty nation?

In this section we focus on the effects of differences in the rates of pure time preference. We keep all other characteristics, such as utility functions, damage functions and production functions identical. Studying the properties of steady states in this case is interesting for at least two reasons. First, economists have been preoccupied with this issue in a trade context for a very long time. A seminal publication in this field is by Stiglitz (1970), who studies cross-country differences in discount rates in a Solow-Heckscher-Ohlin model. Second, environmental economists have had a long tradition of interest in the magnitude of the discount rate. This is mainly because many environmental problems come into play in the far future and are likely to be with us for many generations to come. Surprisingly, differences in the pure rate of time preference between regions and countries are not very often considered in the field. Our specification of damage and the role of the polluting input in production is rather simple, but having said that, we still feel that our basic setting is interesting enough to study the relation between regional differences in discount rates on the one hand and its effects on regional pollution flows on the other hand.

We consider the case where $\rho > \rho^*$. In the long run $\rho + \delta = r > \rho^* + \delta = r^*$. Define ω^*, ϑ^* in a way analogous to ω, ψ. Moreover, $D'(Z^*) = \lambda^* \vartheta^*$ with $\lambda^* = \lambda$, from utility maximization.

We cannot have incomplete specialization in both countries, because that would require equal interest rates.

Proposition 4. *If $\rho + \delta > \rho^* + \delta$ then factor price equalization across countries in the steady state breaks down. At least one country will specialize completely.*

Proof *Since $\rho > \rho^*$ we have that $r > r^*$. This proves the first part of the proposition. Suppose that both countries are imperfectly specialized. Then (r, ϑ) as well as (r^*, ϑ^*) are on the factor price frontier of F as well as on the factor price frontier of pG, which is not possible. This completes the second part of the proof.*

We show that in principle three steady state trade constellations are feasible.

Proposition 5. *If $\rho + \delta > \rho^* + \delta$ the global steady state has only three possible configurations:*
a) imperfect specialization by Home and perfect specialization by Foreign in the clean good: FGF^*
b) imperfect specialization by Foreign and perfect specialization by Home in the dirty good: GF^*G^*
c) perfect specialization by both countries: Home (Foreign) produces the dirty (clean) good: GF^*

Proof Suppose $F > 0$. Then $\vartheta^* \geqslant \vartheta$ because otherwise foreign can make unbounded profits in the clean good production. If $G^* > 0$ then the pair (r, ϑ) lies below the factor price frontier corresponding with pG. This is not feasible. Hence $G^* = 0$. Hence $G > 0$ and $F^* > 0$, the latter holding since the foreign country will use its capital. Suppose $F = 0$. Then it follows that $G > 0$ and $F^* > 0$. Then $\vartheta \geqslant \vartheta^*$. It is possible that $G^* > 0$. So we have either GF^*G^* or GF^*. This completes the proof.

The analysis of the different cases is analogous to what we did for equal rates of time preference. The straightforward generalization of (3.28) becomes

$$\begin{aligned}\delta(K + K^*) &= Z_x(f(\omega) + h(p)g(\psi)) + Z_x^*(f(\omega^*) + h(p)g(\psi^*)) \\ &\quad -h(p)Zg(\psi) - h(p)Z^*g(\psi^*)\end{aligned}$$

Unfortunately Z and Z^* are no longer uniform over the regimes. Nevertheless, bearing this in mind, we can derive the conditions for which each of the regimes prevails.

Case a. (FGF^*). Consider the steady state with $F > 0$, $G > 0$, $F^* > 0$, $G^* = 0$. In the case at hand, $K^* = \omega^* Z^*$ and $Z_x^* = Z^*$. So, the two equations (3.27) and (3.28) now become

$$K = (\omega - \psi)Z_x + \psi Z$$

$$\delta K = (f(\omega) + h(p)g(\psi))Z_x + Z^* f(\omega^*) - Zh(p)g(\psi) - Z^*\delta\omega^*$$

To have an interior solution, with $0 < Z_x < Z$ we need

$$Z^* f(\omega^*) - Zh(p)g(\psi) < Z^*\delta\omega^* + Z\delta\psi$$

This condition is similar (identical for $Z = Z^*$) to the condition $f(\omega) - h(p)g(\psi) < (\omega + \psi)\delta$ that was needed for the existence of this type of equilibrium with equal discount rates.

Case b. (GF^*G^*). Next, suppose that there is a steady state with $G > 0$, $F^* > 0$, $G^* > 0$. Then

$$K^* = (\omega - \psi)Z_x + \psi Z$$

$$\delta K^* = (f(\omega^*) + h(p)g(\psi^*))Z_x^* - Zh(p)g(\psi) - Z^*h(p)g(\psi^*) - Z\delta\psi$$

A necessary and sufficient condition for an interior solution for home pollution and capital is

$$Z^*f(\omega^*) - Zh(p)g(\psi) > Z^*\delta\omega^* + Z\delta\psi$$

Case c. (GF^*). Complete specialization offers an interesting case. Clearly we must have $G > 0$, and $F^* > 0$. Then K/Z is a function of p through $pg'(\psi) = \rho + \delta$ and ϑ is also a function of p through $\vartheta = p[g(\psi) - g'(\psi)\psi]$. We find K^*/Z^* and ϑ^* through $f'(\omega^*) = \rho^* + \delta$ and $f(\omega^*) - f'(\omega^*)\omega^* = \vartheta^*$. Again $\lambda = \lambda^*$ and they follow from utility maximization, as a function of p. Then we find Z and Z^* using $D'(Z) = \lambda\vartheta$ and $D'(Z^*) = \lambda\vartheta^*$, both as a function of p. We also have, as before,

$$\delta(K/Z)Z + \delta(K^*/Z^*)Z^* = Z^*f(K^*/Z^*) - h(p)Zg(K/Z)$$

This can be written as

$$Z^*f(\omega^*) - Zh(p)g(\psi) = Z^*\delta\omega^* + Z\delta\psi$$

Since all variables involved only depend on p we can solve for p and subsequently for all other variables. This then yields a unique set of initial capital stocks for which complete specialization prevails in a steady state. Of course it has to be checked whether the price is in between the prices prevailing in the relevant cases of incomplete specialization.

These results are summarized in

Proposition 6. Suppose $\rho > \rho^*$. Then in the global steady state Home will be a Pollution Haven. In addition, we can categorize the following long-run specialization patterns:

Normal Pollution Haven (FGF^*): Home produces both goods and Foreign produces only clean goods if

$$Z^*f(\omega^*) - Zh(p)g(\psi) < Z^*\delta\omega^* + Z\delta\psi$$

True Pollution Haven (GF^*G^*): Home produces only dirty goods and Foreign produces both goods if

$$Z^*f(\omega^*) - Zh(p)g(\psi) > Z\delta\psi + Z^*\delta\omega^*$$

Several remarks are in order.

1. We use an example to illustrate the possibility of complete specialization. Take $U = C_x^\alpha C_y^{1-\alpha}$, $D(Z) = \frac{Z^{1+\eta}}{1+\eta}$, $F(K_x, Z_x) = K_x^\beta Z_x^{1-\beta}$ and $G(K_y, Z_y) = K_y^\gamma Z_y^{1-\gamma}$ with $0 < \alpha < 1$, $\eta > 0$ and $0 < \gamma < \beta < 1$. With complete specialization we have

$$\frac{K}{Z} = \left(\frac{\rho+\delta}{\gamma p}\right)^{\frac{1}{\gamma-1}}; \vartheta = p(1-\gamma)\left(\frac{\rho+\delta}{\gamma p}\right)^{\frac{\gamma}{\gamma-1}}$$

$$\frac{K^*}{Z^*} = \left(\frac{\rho^*+\delta}{\beta}\right)^{\frac{1}{\beta-1}}; \vartheta^* = (1-\beta)\left(\frac{\rho^*+\delta}{\beta}\right)^{\frac{\beta}{\beta-1}}$$

Also

$$\lambda = \lambda^* = \alpha^\alpha(1-\alpha)^{1-\alpha}p^{\alpha-1}$$

Therefore

$$Z^\eta = \alpha^\alpha(1-\alpha)^{1-\alpha}p^{\alpha-1}p(1-\gamma)\left(\frac{\rho+\delta}{\gamma p}\right)^{\frac{\gamma}{\gamma-1}}$$

and

$$(Z^*)^\eta = \alpha^\alpha(1-\alpha)^{1-\alpha}p^{\alpha-1}(1-\beta)\left(\frac{\rho^*+\delta}{\beta}\right)^{\frac{\beta}{\beta-1}}$$

Moreover,

$$C_y + C_y^* = G$$

$$C_x + pC_y = pG - \delta K$$

$$C_x^* + pC_y^* = F^* - \delta K^*$$

implying

$$(1-\alpha)\delta K = (1-\alpha)F^* - \alpha pG - (1-\alpha)\delta K^*$$

So,

$$\begin{aligned}(1-\alpha)\delta(K/Z)Z &= (1-\alpha)Z^*F(K^*/Z^*,1)\\ &\quad -\alpha pZG(K/Z,1) - (1-\alpha)\delta(K^*/Z^*)Z^*\end{aligned}$$

The expressions for K/Z and K^*/Z^* as functions of p only are known. This then leads to the following equation for p:

$$\left(\frac{p^{\frac{1}{1-\gamma}}(1-\gamma)\left(\frac{\rho+\delta}{\gamma}\right)^{\frac{\gamma}{\gamma-1}}}{(1-\beta)\left(\frac{\rho^*+\delta}{\beta}\right)^{\frac{\beta}{\beta-1}}}\right)^{1/\eta} = \frac{(1-\alpha)\left(\frac{\rho^*+\delta}{\beta}\right)^{\frac{\beta}{\beta-1}} - \delta(1-\alpha)\left(\frac{\rho^*+\delta}{\beta}\right)^{\frac{1}{\beta-1}}}{\alpha p^{\frac{1}{1-\gamma}}\left(\frac{\rho+\delta}{\gamma}\right)^{\frac{\gamma}{\gamma-1}} + \delta(1-\alpha)p^{\frac{1}{1-\gamma}}\left(\frac{\rho+\delta}{\gamma}\right)^{\frac{1}{\gamma-1}}}$$

From this we can solve p and subsequently Z and Z^*. Finally we can find the K and K^* needed for this equilibrium to occur.

2. Proposition 6 reveals two interesting tendencies with respect to the patterns of production and trade when Home is more impatient than Foreign. Firstly, the tendency towards a more specialized production pattern. Why is this the case? Imperfect specialization becomes impossible since factor prices are no longer equalized. Hence, at least one of the two countries becomes perfectly specialized. In addition, the global production pattern is more orientated towards the relatively dirty good. With the world now being more impatient 'on average' we find that ceteris paribus the steady state levels of capital are lower. From the Rybczynski theorem we then know that world production will increase in the direction of the dirty good, and more than proportionally so. Secondly, the direction of the inequality $\rho \gtrless \rho^*$ is a predictor of the trade pattern. Hence, in the long-run the relatively impatient country will be a pollution haven. Note that this observation is independent of the specific trade pattern that comes about. The previous proposition showed that if $\rho > \rho^*$ home (foreign) is always a producer of the dirty (clean) good. From this it directly follows that home will always be an exporter of the dirty good. Should we expect this result to go through in more general models? Not necessarily. Our model has assumed the accumulation of a perfectly clean factor. Various additions to the literature on trade and the environment have assumed a correlation between capital-intensity and emission intensity in models with three factors of production (labor, capital and emissions) (Copeland and Taylor, 2003). Incorporating this correlation into our model might lead us to find that the patient country will be an exporter of the dirty good. This would overturn our finding.

3. We can conveniently illustrate some of our findings in an (r, ϑ)-diagram. In Figure 3.3 we have depicted the factor price frontier of F and we have fixed $r = \rho + \delta$ and $r^* = \rho^* + \delta$. The points E_1 correspond with an equilibrium where $F > 0$, $G > 0$ and $F^* > 0$. For both countries the factor prices are on the FPF of F and the FPF of pG goes through the point E_1 at which it is not profitable for the foreign country to engage in dirty production. It is immediately clear that $\vartheta < \vartheta^*$, implying $Z < Z^*$. Hence the patient country is suffering more pollution. The points E_2 correspond with $F = 0$, $G > 0$, $F^* > 0$ and $G^* > 0$. Now it is not profitable (in a strict sense) for Home to produce the clean commodity. The latter configuration can also correspond with complete specialization. However, a clear cut example of an equilibrium with complete specialization is given by the points E_3. Here the home country only produces the dirty commodity. Again the foreign country experiences more pollution than the home country. The graph also shows that the pollution rates are no longer uniform over the regimes. For example, moving from E_1 (hence FGF^*) to E_2 (hence GF^*G^*) implies an increase of the price p. This

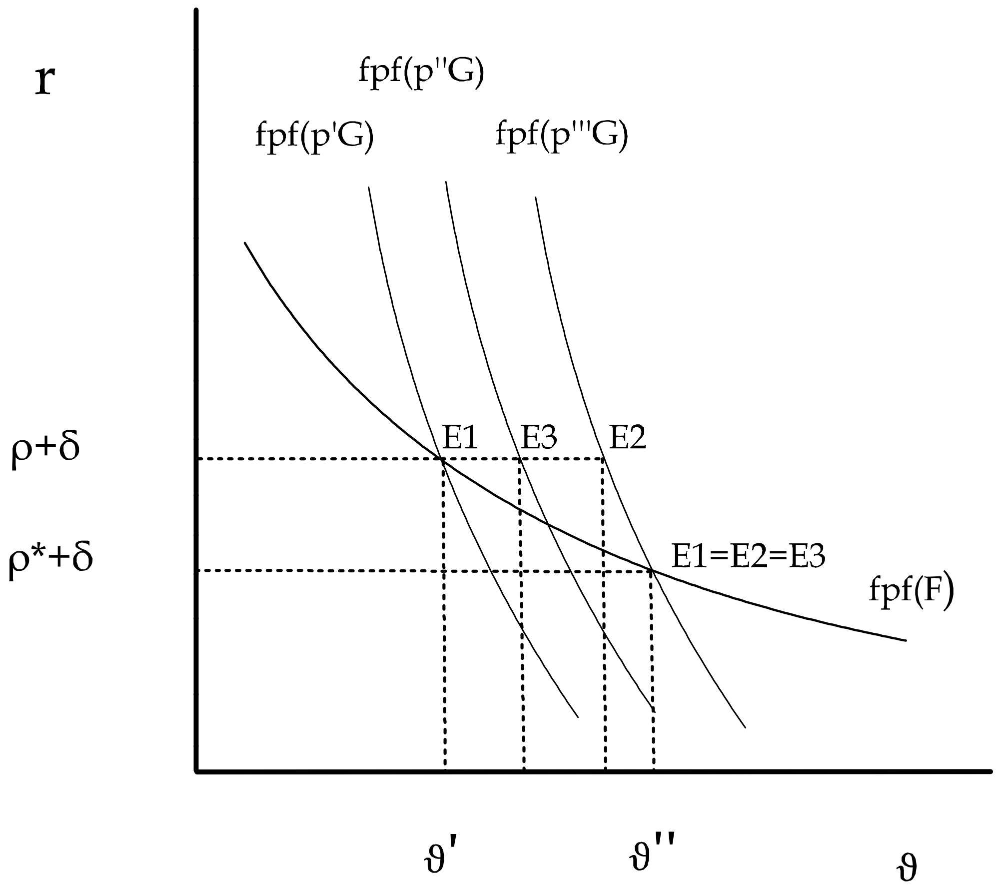

Figure 3.3: Home is Impatient

is accompanied by a decrease in the marginal utility of the dirty commodity λ. But ϑ^* does not change. Hence, pollution in the foreign country decreases. Let us focus on the intuition behind the emergence of the three different specialization patterns. First, note that Home (Foreign) will always produce the dirty (clean) good. The reason is that the relatively patient country will have accumulated a relative large capital stock in the steady state. Ceteris paribus this implies that Foreign, the relatively patient country, will have a comparative advantage in the clean good. Second, what determines the exact specialization pattern in the steady state are the consumer preferences. In the case of the Cobb-Douglas utility function above, α indicates the relative preference for the clean commodity. Therefore, an increase in α will increase the likelihood of a normal pollution haven, where both countries produce the clean commodity. A further sensitivity analysis is subject to further research. But it can be shown that for $\rho > \rho^*$ ($\rho < \rho^*$) an increase (decrease) in relative environmental preferences η^*/η will increase the likelihood of both countries producing the dirty good in the steady state.

3.6 Conclusion

The question of who produces what for whom becomes especially interesting when the 'what' involves environmental degradation. With the rise of China as the manufacturer of the world this question has become all the more pressing. No wonder that the topic of trade and the environment continues to evoke discussion in environmental economics. In this chapter we have tried to give what we hope is a new and interesting perspective on the pollution haven hypothesis. We have done so by emphasizing the dynamic nature of the problem. In our view this asks for an integrated picture of trade, growth and the environment. Our main method of analysis is dynamic trade theory. We construct a two-country Ramsey-Heckscher-Ohlin model with pollution to consider (i) long-run specialization patterns when countries are completely identical and (ii) the effects of cross-country differences in the subjective discount rate on long-run trade patterns. First, we find that with identical countries there are several long-run equilibria but none with perfect specialization by both countries. All steady states are characterized by factor price equalization. Interestingly, the steady state level of flow pollution is independent of the specific specialization pattern that is obtained. Second, we find that if countries differ with respect to the rate of time preference, an important and deep parameter in environmental economics, at least one country will specialize completely. This holds for the model in general as well as for the steady state. It opens up the possibility for so-called true pollution havens: complete specialization in production of the dirty good by the impatient country. This contrasts with earlier results in the literature that stressed imperfect specialization by all trade partners. Since the dirty good is used only for consumption, true pollution havens are more likely when consumer preferences for the dirty good are relatively high.

In the previous sections we discussed various long-run implications of our dynamic trade model. Interesting as this may be, we have not yet explored local and global dynamics. For example, the question whether a country will always be a pollution haven once it has 'started out' as one, cannot be answered without referring to transitional dynamics. In future work we hope to address these issues in framework(s) that are closely related to the one that we have set out in this chapter. More in general, theoretical research in the trade-growth-environment nexus has primarily delivered papers that are either 'trade' or 'growth', but not both. Although such a strict focus has led to many interesting insights, there are theoretical and empirical reasons that demand an integrated approach.

From a theoretical point of view one can disentangle two reasons for an integrated approach. First, asking old questions in a new framework might yield important new results by itself. For example, the Green Solow model (Brock and Taylor, 2008) shows us that a rather standard growth model with diminishing returns to capital and technological progress in abatement yields an environmental Kuznets curve. It also explains that the point in time that is associated with a peak level of emissions depends on initial conditions. An integrated model of the world economy might yield several new insights in this area. One might be able to derive an EKC for the world as a whole and relate it to the distribution of production and income across countries. Can an EKC for the world as a whole be consistent with periods where emission levels increase for one country while they are decreasing for another? And how is the cross-country timing of peak levels in emissions affected by international trade? How are export patterns related to (relative) emissions growth rates across countries? Can a country that is on the downward sloping part of its EKC still be a pollution haven?

Second, an integrated approach allows us to ask questions that are new by itself. For example, empirical evidence indicates that emissions intensity differs more across countries than across industries. In addition, there is evidence that laggard countries adopt cleaner technologies at a lower level of income than early adopters. Is it possible to come up with a coherent explanation of these two facts? One possibility is to construct a dynamic trade model where capital is heterogeneous, i.e., vintage capital. Many technologies, environmental or otherwise, are embodied in capital equipment. For example, empirical evidence for the U.S indicates that capital investment is responsible for more than 50% of technological progress (Greenwood et al., 1997). If technology is embodied in capital, then at any given point in time developing countries will use older, dirtier vintages for production because they are cheaper than new vintages and environmental regulation is less stringent in these countries. At the same time, developing countries will start to implement cleaner technologies at an earlier phase in their development process than developed countries once did, simply because they do not have to 'push' the technology frontier themselves. A recent paper by Eaton and Kortum (2001) might be useful in this regard. Finally, empirical methodologies that are constructed by applying closed economy models are no substitute for ones that are derived from open economy models. We hope to explore some of these abovementioned questions in future work.

Chapter 4

Does Corruption Discourage International Trade?[1]

‘If I am born again, I want to come back as a customs official.’

Anonymous Thai Businessman[2]

4.1 Introduction

There is a “mystery of missing trade” (Trefler, 1995): the volume of international trade is much less than predicted by economic theory. Eaton and Kortum (2002) suggest that trade would be five times as large as presently observed volumes, if trade were “frictionless”. In particular, trade flows involving low-income countries are relatively small (see United Nations, 2007). The missing trade points to the relevance of various inhibiting barriers (De Groot et al., 2004). Corruption in particular results in unreported trade. In low-income countries in which a relatively large share of government revenue is collected through customs, corrupt customs officials underreport trade and deprive the government of revenue.

However, already as early as in 1957 did The Economist suggest that bribe paying may have positive effects. It refers to the Russian civil servant as “ (t)he ‘fixer”, or contact man who, for due reward, will help win the ear of authority or otherwise further his client’s aims” (The Economist, 1957, p. 491). “The bureaucrats’ main work is “settling the problems” (reshat’voprosy). So in fact high personal power fills the gap between formal and informal rules” (Dubrovskiy, 2006, p. 8). Levy (2007) presents anecdotal evidence and personal experience during the years 1960-1971 of the efficiency enhancing illegal activities in the Republic of Georgia.

In such a rent-seeking society, reforms are very difficult to implement. Hillman and Schnytzer (1986), for example, describe the detrimental effects of attempts to curb corruption in one of Moscow’s food stores. At the end, the reformer had to accept a compromise in order to let the food store function properly. These examples are from a period where these countries were centrally planned economies.

[1]This chapter will also appear as de Jong & Bogmans (forthcoming)

[2]Quote taken from Gatti (1999).

Since then, market forces have been introduced. This change does not imply, however, that the mechanism described by Hillman and Schnytzer (1986) and Levy (2007) are not relevant anymore. On the contrary: the failure of the “contraband STOP” campaign implemented after the Orange Revolution of 2004/2005 in the Ukraine illustrates the topicality of these incentives (Dubrovskiy, 2006). Before the campaign, many waivers softened the consequences of prohibitive import tariffs and a complicated tariff structure, but also provided fertile ground for corruption. The campaign targeted mainly at smuggling and no measures were taken to substitute corruption in its important social role of easing an inefficient trade policy. As a result, the overall initial outcome was negative. “The import of goods was largely complicated and virtually stopped for several weeks: prices on many goods, primarily meat products, increased; many firms went bankrupt due to the sudden change in the rules of the game; lines at customs increased tremendously; and so on.” Dubrovskiy (2006, pp. 9 and 10). The reforms did not change the culture of rent seeking, and thus resulted in a poor economic performance. In such a case, the message by The Economist (1957), Hillman and Schnytzer (1986), Leff (1964), and Levy (2007) holds, namely bribery can be a compensation for bad - unnecessarily complicated in this case - formal institutions.

Various other studies have investigated this possibility. The positive effects of corruption have been found in case studies and in cross-country regression analyses (Dubrovskiy, 2006; Heidenheimer, 1970, pp. 479-486). Cross-country regression analyses confirming the positive influence of corruption include Méon and Weill (2008) for efficiency; Aidt et al. (2008) and Méndez and Sepúlveda (2006) for growth, Mironov (2005) for growth and capital accumulation; and Egger and Winner (2005) for foreign direct investment. Often the positive effects are found when institutions are bad or regulation is very complicated. Others, however, do not find evidence of a positive influence (Mauro, 1995; Ades and di Tella, 1999; Méon and Sekkat, 2005). Kaufman and Wei (1999) use firm level data to affirm that corruption is disadvantageous. In acts of rent seeking, firms that pay more bribes are also likely to spend more management time with bureaucrats. Hence, as the theoretical arguments (see Aidt, 2003) suggest, the empirical results are mixed.

In some cases the bribe to be paid is known in advance and sometimes not. This is an important distinction. Uncertainty associated with chaotic and arbitrary corruption is expected to reduce international trade further (Bügel, 2010; Herrera et al., 2003; Mauro, 1998; Myint, 2000; Shleifer and Vishny, 1993). Organised (or collusive) corruption is predictable: business persons know in advance the size of bribes, whom to bribe, and the service delivered. In contrast, in an unorganised system of corruption, businesspersons are less certain about the services provided and the frequency of bribing. Officials (operating on their own ‘islands’) do not know what others charge, which leads to overcharging. Traders who deal with low-income countries are often uncertain about what to expect when dealing with customs (see Cunningham, 1996, quoted by Finger and Schuler, 1999, p. 7). They thus have to take additional measures, such as taking sufficient amounts of cash with them in case they have to bribe many officials, devoting time to negotiations on the conditions of the illicit transaction, and monitoring the settlement. Risk-averse businesspersons may choose not to do business in a country with such a system.

Summing up, corruption is predicted to reduce the volume of international trade. On the other hand, if the quality of customs is low and the tariff structure complicated, corruption can facilitate international trade. Uncertainty about the process of corruption, however, reinforces the arguments for a negative effect of chaotic corruption on trade.

The empirical studies referred to above use measures representing corruption in general, which is assumed to be correlated with corruption at the border. A measure of corruption at the border is of course preferable. Iwanow and Kirkpatrick (2007) use trade-specific indices but restrict their analysis to institutions and construct an index, so that the effects of specific items cannot be tested.

We use measures of specific forms of corruption at the border and of the quality of customs rather than corruption and the quality of institutions in general. We apply the measures to studying the effect on international trade of i) the level of corruption, ii) the quality of institutions facilitating international trade, iii) the interaction between corruption and the quality of the institutions, and iv) the degree of unpredictability of corruption.

In the next section, we describe the data and in Section 3 the econometric methods used. Thereafter, we discuss the empirical evidence with respect to the effects on international trade of: the level of corruption (Section 4), corruption under “bad” institutions (Section 5), and the unpredictability of bribe paying (Section 6). Section 7 provides concluding remarks.

4.2 Data on corruption and quality of customs

The dependent variable is the average over the years 1999 to 2002 of bilateral exports of total commodities from the UN COMTRADE database. The information on corruption at the border and quality of customs is from the World Business Environment Survey (WBES) conducted by The World Bank. The survey contains data for about eighty countries. For each country, about 100 business firms were interviewed on various topics and the answers transferred to an average score per country. The exact wording of the questions is in Appendix A. Appendix C contains a list of countries included in the regressions.

We use nine indices for measuring different aspects related to corruption in a country. The first is the Corruption Perceptions Index (CPI), issued by Transparency International. It ranges from 0 (highly corrupt) to 10 (almost clean). The second index contains the scores of countries on the control of corruption index, which ranges from -2.5 to 2.5, with higher values corresponding to better governance. These two measures of the seriousness of corruption in countries are very highly correlated (correlation coefficient of 0.95), indicating that there is great consensus amongst observers about levels of corruption.

The other measures of corruption are from the WBES. Two questions are part of the module on Bureaucratic Red Tape. They are listed here in the same order has they have been asked. The first indicator measures how often businesspersons need to pay irregular extra unofficial payments. It ranges from 1 (always) to 6 (never). The next one is a follow up question whether businesspeople usually know in advance about how much this ‘additional payment’ is. It also ranges from 1 (always) to 6 (never). One can regard the answers to this question as a measure of the predictability of corruption. Two other measures of the government’s predictability are taken from the module on Predictability. The first refers to economic predictability and asks whether the respondent is confronted with unexpected changes in economic and financial policies. The second asks whether the respondent is confronted with unexpected changes in rules and regulations. In both cases the higher the score, the less predictable policy is. One can imagine that the probability of corruption increases, if civil servants have discretionary rights and are not corrected by superiors or independent supervisors. We therefore also test the influence of the answer on the question: ‘If a government agent acts against the rules, I can usually go to another official or to his superior and get the correct treatment without recourse to unofficial payments.’ Scores range from 1 (always) to 6 (never is there such a possibility).

Three questions in the WBES explicitly refer to corruption at the border and the quality of customs. The first is the frequency of payments to customs authorities. The scores range from 1 (always) to 6 (never). The second variable is the numbers of days that it typically takes from the time the goods arrive in their point of entry (e.g. port or airport) until the time a trader can claim them from customs. The scores are in days.[3] The final variable gives an overall picture of the quality and efficiency of services delivered by the customs agency. Scores range from 1 (very good) to 6 (very bad).

An advantage of the WBES data is that the questions are specifically referring to the respondents‘ own experience. The questions contain phrases such as ‘in my line of business’, ‘do firms like yours’, ‘I can usually’, and ‘do you regularly have to cope with .. which materially effects your business?’. So, the questions are asking for incidences affecting the respondents themselves and do not refer to a general feeling. In this way, this dataset supposedly refers to facts, whereas the other indices refer to perceptions.

Unfortunately, the WBES data are not available for all countries for which we have data on bilateral trade flows. Moreover, for some countries answers on a particular question are missing. This leads to different numbers of observations for each relation estimated, so that the results could be influenced by the number of countries included in the estimation of the particular equation. To analyse the results' sensitiveness to different numbers of observations, per table we also present the results for the common dataset.

National authorities collect the trade data. Of course, due to corruption, the reported trade flows may differ from actual ones, so that we have to consider the possible consequences for this measurement bias. The extent to which corruption leads to a difference between actual and reported data depends on the aim of corruption. If bribe payment only aims at speeding the procedures, then the probability of under-reporting is less than when traders have an incentive to change the type of registration of the goods. Due to different tariffs per type, traders might bribe custom officials to change the goods’ registration. In case of high tariffs, they might even smuggle goods into the country (see Farzanegan, 2009 for explanatory factors of illegal trade). These disadvantages are less relevant when the traders’ aim is just to speed up the procedure, so to buy time, which is often found to be an important element in international trade (see Djankov et al., 2006 and Hummels, 2001). Of course, fast procedures can lead to a lower level of registration, but we expect it to be less important when a lower registration is the briber’s main aim. The disadvantage of misreporting and underreporting are most pertinent to studies that differentiate between different categories of goods. We use the market value of the total flow of goods as the dependent variable, so that this disadvantage is expected to be less important. It still could be, however, that bribes are paid in order to circumvent the registration of goods. Then the reported flows would be smaller than the actual ones. Consequently, the negative effects of corruption would be overestimated and the positive effects of corruption would be underestimated.

[3] All scores with the value ‘97’ (days) are missing values and were deleted from the data set.

4.3 Econometric methods

As far as we know, all empirical studies on the relationship between international trade and the quality of institutions use the gravity model. In order to be able to compare our results with those found by others, we use the gravity model in this study as well. The gravity equation can be derived as the reduced form of new trade models (Redding and Venables, 2004, and Feenstra, 2004, Ch. 5) and of the Heckscher-Ohlin trade theory under perfect competition (Deardorf, 1998). This equation is called the workhorse of applied international economics (Eichengreen and Irwin, 1998). The typical gravity equation is:

$$\begin{aligned} \ln(E_{ij}) &= \beta_0 + \beta_1 \ln(Y_i) + \beta_2 \ln(Y_j) + \beta_3 \ln(y_i) + \beta_4 \ln(y_j) + \beta_5 D_{ij} \\ &\quad + \beta_6 Border_{ij} + \beta_7 \textit{Comlang}_{ij} + \beta_8 \textit{Comcol}_{ij} \\ &\quad + \beta_9 \textit{Colony}_{ij} + \beta_{10} \textit{Corr}_i + \beta_{11} \textit{Corr}_j + \varepsilon_{ij} \end{aligned} \tag{4.1}$$

where i and j denote the importing and exporting country, respectively. E_{ij}, the dependent variable, is the average of total exports from j to i during the years 1999 to 2002. By taking the average over some years we avoid biases due to year specific circumstances. The independent variables are, respectively: national income represented by GDP (Y), national income per capita (y), the distance between i and j (D_{ij}), dummy variables indicating whether the two countries share a common border ($\textit{Border}_{ij}$), a common language ($\textit{Comlang}_{ij}$), have had a common colonizer after 1945 ($\textit{Comcol}_{ij}$), have ever had a colonial link ($\textit{Colony}_{ij}$) and the corruption variables ($\textit{Corr}_i$ and $\textit{Corr}_j$). The last term, ε_{ij}, is the error term and is assumed to be well behaved. By including corruption in both the importing and exporting country, we at least partially take into account the presence of regional corruption (see Becker at al., 2009 for evidence on regional corruption).

Essentially, equation (4.1) consists of the basic gravity equation, which neglects border effects, supplemented with a series of variables representing the effects of borders and of corruption in the importing and exporting country. Anderson and Van Wincoop (2003) use a general equilibrium model that gives a theoretical foundation for the gravity equation that explicitly considers border effects. Their model includes for each trade flow a term representing the bilateral trade costs relative to the multilateral trade costs: bilateral trade resistance compared to multilateral trade resistance. Trade between two countries will be lower if bilateral trade costs are high relative to the average costs of trade. Baier and Bergstrand (2009) propose a linear approximation of these relative trade resistance terms, which results in a reduced-form gravity equation that can be estimated by Ordinary Least Squares (OLS). In their approach, the average trade costs of all countries are subtracted from the sum of the average trade costs of the two countries (see Baier and Bergstrand, 2009, p. 80). The equation to be estimated is then:

$$\begin{aligned} \ln(E_{ij}) &= \beta_0 + \beta_1 \ln(Y_i) + \beta_2 \ln(Y_j) + \beta_3 \ln(y_i) + \beta_4 \ln(y_j) + \beta_5 D_{ij}^{BB} \\ &\quad + \beta_6 Border_{ij}^{BB} + \beta_7 \textit{Comlang}_{ij}^{BB} + \beta_8 \textit{Comcol}_{ij}^{BB} \\ &\quad + \beta_9 \textit{Colony}_{ij}^{BB} + \beta_{10} \textit{Corr}_i + \beta_{11} \textit{Corr}_j + \varepsilon_{ij} \end{aligned} \tag{4.2}$$

where the superscript ^{BB} indicates that the Baier-Bergstrand transformation has been applied. Equation

(4.2) is estimated in this chapter with simple averages used for calculating the relative trade resistance terms; the BB-terms in equation (4.2).

The hypotheses are tested by means of data on bilateral exports. The use of bilateral exports enables us to investigate the influence of corruption in importing and exporting countries separately.[4] Moreover, it corresponds with the theoretical framework of the gravity function - which we will use - and thus prevents us from making the "silver medal mistake" (Baldwin and Taglione, 2006). Models of bilateral flows have the same observations (country characteristics) repeatedly as an explanatory variable; characteristics of the Germany economy influence exports from Germany to and imports into Germany from all other countries. Consequently, the correlation of bilateral trade flows involving Germany will be higher than that between flows from randomly selected countries. Ordinary Least Squares (OLS) estimates of these flows are unbiased but underestimate the coefficients' standard deviation. As in e.g. Anderson and Marcouiller (2002) and Berkowitz et al. (2006), we therefore correct the coefficients' standard deviation for this clustering of observations and investigate the sensitiveness of the results for this correction.[5]

One could argue that corruption and international trade are simultaneously determined; trade is high in countries with low levels of corruption, and high (low) levels of trade reduce (increase) corruption. An instrumental variables approach would eliminate the bias resulting from endogeneity. It reduces, however, the estimator's efficiency. Hence, one has to test the endogeneity of the corruption variable and the quality of the instrumental variables. The latter should be correlated with corruption but uncorrelated with the trade flows. We have used Sargan's C statistic for testing the endogeneity of the corruption variable. Often the corruption variable appeared to be exogenous so that OLS is to be preferred to IV. When the C-statistic indicated the possibility of an endogenous corruption variable, we tested whether the instrumental variables were highly correlated with the corruption variable and uncorrelated with the trade flows. The instruments considered correlate with trade flows. The instruments considered are: the percentage of the population belonging to a certain religion (Protestant, Catholic, Muslim, Orthodox, Hindu and nonreligious), the origin of law (English, French, German and Scandinavian), the population density, the country's area in square kilometres, and ethnic fractionalization. Instead of the traditional IV method, we have estimated the relations by means of the Hausman-Taylor Method (HTM) set out in Egger (2005). The HTM employs an instrumental variables approach to eliminate correlation between (a subset of) the explanatory variables and the unobserved country specific effects that might bias standard OLS or Random Effects (REM). The HTM constructs instruments exclusively from inside the model. The specific estimator implemented here allows for both importer and exporter specific effects (two-way).

Relation (4.2) is estimated with different techniques: OLS, OLS with correction for clustering by importers, OLS by clustering for exporters, a Hausman-Taylor estimator with corruption as an exogenous variable, and finally this estimator with corruption as endogenous. Table 4.1 contains the full results of each of these estimation techniques for the equation in which corruption is represented by control of

[4]We thank an anonymous referee for this suggestion. As far as we know Berkowitz et al. (2006) and Bügel (2010) are the only other papers that make a distinction between exporters and importers. Both papers, however, do not study bribery but only discuss characteristics of institutions.

[5]To illustrate the importance of correction for clustering, we re-estimated the results in Wei (2000) and found that this correction reduces the coefficients' significance considerably. The t-values decreased from more than 5 to slightly more than 2.

	(1)	(2)	(3)	(4)	(5)
Conc$_{imp}$	0.198***	0.198	0.198***	-0.373**	0.835
	(6.08)	(1.93)	(5.04)	(-2.06)	(1.38)
Conc$_{\text{exp}}$	0.327***	0.327***	0.327*	-0.338*	-1.515***
	(9.47)	(8.30)	(2.60)	(-1.82)	(-5.71)
Ln(Y$_{imp}$)	0.781***	0.781***	0.781***	0.704***	0.825***
	(76.68)	(26.81)	(37.71)	(32.11)	(17.72)
ln(y$_{imp}$)	-0.0243	-0.0243	-0.0243	0.552***	-0.222
	(-1.05)	(-0.36)	(-0.84)	(3.94)	(-0.52)
Ln(Y$_{\text{exp}}$)	1.070***	1.070***	1.070***	1.261***	1.069***
	(94.71)	(53.41)	(26.55)	(40.40)	(30.32)
Ln(y$_{\text{exp}}$)	-0.191***	-0.191***	-0.191*	0.398***	1.155***
	(-6.93)	(-6.49)	(-2.25)	(2.62)	(5.77)
D^{BB}	-0.235***	-0.235***	-0.235***	-0.197***	-0.186***
	(-39.44)	(-20.61)	(-14.16)	(-41.50)	(-32.54)
Border^{BB}	2.070***	2.070***	2.070***	2.237***	2.230***
	(18.77)	(16.72)	(13.04)	(21.89)	(20.74)
Comlang^{BB}	0.375***	0.375***	0.375***	0.474***	0.509***
	(5.43)	(4.26)	(3.55)	(8.16)	(7.98)
Comcol^{BB}	1.216***	1.216***	1.216***	1.467***	1.337***
	(13.49)	(7.35)	(7.97)	(17.08)	(14.83)
Colony^{BB}	0.901***	0.901***	0.901***	0.976***	0.997***
	(7.13)	(5.62)	(6.09)	(6.91)	(6.53)
Constant Term	-28.22***	-28.22***	-28.22***	-25.11***	-16.69***
	(-72.21)	(-31.76)	(-22.84)	(-25.60)	(-14.70)
R^2	0.66	0.66	0.66	0.59	0.50
N	10250	10250	10250	10250	10250

Table 4.1: The effect of control of corruption on bilateral trade in 1999-2002: Various estimation techniques. Note: t-statistics are reported in parentheses in the line below the parameter estimates. Standard errors are corrected for heteroscedasticity by White's procedure. In column (2) the coefficients' standard errors are corrected for clustering by importer and in column (3) by exporter. Hausman-Taylor estimations using Egger (2005)'s procedure with corruption (4) exogenous and (5) endogenous. ***: significant at the 99% confidence level **: significant at the 95% confidence level,*: significant at the 90% confidence level. Symbols: ln(.) logarithm; subscript 'imp', importing country; 'exp', exporting country; Y, Gross Domestic Product; y, GDP per capita; Conc, control of corruption; D, distance; Comlang, common language; Comcol, common colony; Colony, colonial link.

corruption. All independent variables of the basic gravity equation are highly significant (Table 4.1, column 1). The regression as a whole explains close to 66% of total bilateral exports (the adjusted R^2 is 0.66). Except for income per capita in the exporting country, all variables have the expected sign; the richer the im- or exporting country, the more they trade and the greater the distance between the two countries, the less they trade. Countries with a common background trade more with each other than countries that do not share these characteristics. The first column presents the results without correction for clustering, the second with correction for clustering by importer, the third by clustering for exporter. The three columns clearly show the effect of correction for clustering; the estimated coefficient is unaffected but the coefficients' standard deviation increases and the significance level decreases for the variables for which the correction is made. That is, the level of significance of the importers' (exporters') coefficients declines if we correct for clustering by importer (exporter). In the basic equation (column 1) better governance - measured by the control of corruption index – in both the importing and exporting country increases trade. For the importing country, this effect becomes insignificant when correcting for clustering by importer (Table 4.1, column 2). When we correct for clustering by exporter, the effect of the control of corruption in the exporting country remains significant (Table 4.1, column 3).

Surprisingly, the HTM does not provide for a particular good fit (the R^2 is 0.59 and 0.50). The absolute values of the coefficients of the corruption variables are highly sensitive to whether corruption is assumed exogenous or endogenous (column 4 and 5 respectively). This is to be expected since we now control for unobservable influences. At the same time, the coefficients of the GDP per capita variables seem very sensitive to this assumption as well. More importantly, a Sargan over-identification test casts doubt on the validity of the instruments and an over-identification test according to Hausman and Taylor (1981) rejects the assumptions of the Hausman Taylor method. We therefore refrain from using the Hausman-Taylor method for the remaining estimations in the sections that follow.

4.4 The level of corruption and international trade

In the remainder of the chapter, we describe the effects of various forms of corruption on imports and exports. We only report the coefficients of the corruption variables. To ease the comparison, the relevant coefficients of control for corruption from Table 4.1 are repeated in column 1 of Table 4.2. This table also reports the results for the corruption perception index and the additional payments required. For all three variables, an increase in corruption reduces trade (an increase in the variables signals less corruption). Corruption in the exporting country remains significant even when we correct for clustering by exporter. The correction for clustering by importers leads to insignificant coefficients for control of corruption and the perception of corruption. The additional payments required remains significant. The level of significance of control of corruption and of the corruption perception index decline when we use only the observations these variables have in common with the additional payments required variables (Table 4.2, lower part). Now, the first two variables are insignificant if we correct for clustering by the relevant type of countries.

Three variables measure the level of corruption directly related to international trade: the frequency of payments to customs, the number of days to import, and an indicator of the quality of customs. The

	(1)	(2)	(3)
Corruption in importing country	0.198	0.283	0.273
	(6.08)***	(3.60)***	(6.95)***
	(1.93)	(1.00)	(3.27)**
	(5.04)***	(3.76)***	(3.85)***
Corruption in exporting country	0.327	0.789	0.369
	(9.47)***	(8.38)***	(8.13)***
	(8.30)***	(8.06)***	(6.67)***
	(2.60)*	(2.62)*	(2.99)**
N	10250	5831	1910
Largest common sample (N=1910)			
Corruption in importing country	0.298	0.275	
	(4.01)***	(1.52)	
	(1.09)	(0.57)	
	(4.19)***	(2.02)*	
Corruption in exporting country	0.393	0.583	
	(4.95)***	(3.39)***	
	(5.15)***	(3.30)***	
	(1.98)	(1.41)	
N	1910	1770	

Table 4.2: Bilateral trade (average 1999 to 2002): corruption in general. Column (1) Control of corruption, (2) Corruption perception index, (3) Additional payments . In each column, we first present the estimated coefficient. Below the coefficient, we present between brackets the absolute value of the t-statistic for the regression with respectively no correction for clustering, correction for clustering by importing country and correction for clustering by exporting country. Standard errors are corrected for heteroscedasticity by White's procedure. ***: significant at the 99% confidence level **: significant at the 95% confidence level,*: significant at the 90% confidence level.

	(1)	(2)	(3)	(4)	(5)
Corruption in importing country	-0.214	-0.381	-0.230	-0.284	0.002
	(3.21)**	(6.13)***	(3.50)***	(5.07)***	(0.01)
	(2.01)*	(2.62)*	(1.45)	(2.07)*	(0.01)
	(3.47)***	(4.82)***	(4.44)***	(4.58)***	(0.02)
Corruption in exporting country	-0.153	-0.309	0.066	-0.223	0.242
	(1.96)	(4.86)***	(0.93)	(3.65)***	(2.01)*
	(2.14)*	(4.57)**	(1.13)	(3.73)***	(2.13)*
	(0.79)	(1.82)	(0.26)	(1.36)	(0.67)
N	2644	3051	3051	2618	2618
Sample restricted to the 2618 observations of columns (4) and (5)					
Corruption in importing country	-0.214	-0.487	-0.277		
	(3.21)***	(7.18)***	(3.92)***		
	(2.01)*	(2.98)**	(1.63)		
	(3.45)**	(5.58)***	(5.13)***		
Corruption in exporting country	-0.192	-0.380	0.078		
	(2.47)**	(5.37)***	(1.01)		
	(2.72)**	(5.47)***	(1.24)		
	(0.99)	(2.09)*	(0.30)		
N	2618	2618	2618		

Table 4.3: Bilateral trade (average 1999 to 2002): corruption at the border. Columns (1) Frequency of payments , (2) log number of days at the border, (3) quality of customs, (4) interaction frequency of payments and log number of days at the border, (5) log interaction frequency of payments and quality of customs. In each column, we first present the estimated coefficient. Below the coefficient, we present between brackets the absolute value of the t-statistic for the regression with respectively no correction for clustering, correction for clustering by importing country and correction for clustering by exporting country. Standard errors are corrected for heteroscedasticity by White's procedure. ***: significant at the 99% confidence level **: significant at the 95% confidence level,*: significant at the 90% confidence level.

last two variables are proxies for the customs' quality. The less frequent bribes are paid the lower trade is (Table 4.3, column 1).[6] This suggests that bribe paying functions as a lubricant. This effect is the largest and always significant for the importing country. For the exporting country, the effect is only significant when we cluster for importer. Its significance increases if we restrict the analysis to the common dataset (Table 4.3, bottom part of column 1). The longer the average waiting time at the border, the less countries trade (Table 4.3, column 2). Once again, this effect is larger and always significant for the importing country. The exporting country's influence is insignificant when we correct for clustering by exporter. This coefficient remains significant if we restrict the analysis to the set of countries for which information on all variables are available (Table 4.3, lower part of column 2). A low quality of customs reduces trade in the importing country (Table 4.3, column 3). The quality of customs in the exporting country does not have any significant effect. This conclusion is unaffected by a reduction to the common sample. In conclusion, the empirical evidence suggests that bribe paying enhances imports, whereas bad institutions - long waiting time at the border and low quality of customs – reduce imports. A long waiting time at the border hampers exports. Regressions using firm level data confirm the detrimental effects of waiting time at the border for exports (see Appendix B), as do results presented in Djankov et al. (2006).

4.5 Can Corruption facilitate trade?

The results of the previous section support the trade-facilitating hypothesis of bribery. Since bad institutions hamper trade, one wonders whether this effect is in particular important for countries with bad institutions. In order to test whether bribery compensates the effects of bad functioning institutions, we construct two interaction variables, representing the interaction between the quality of customs and bribe paying. The quality of customs is measured by waiting time at the border and by the index on the quality of customs. Corruption by means of bribe paying would improve the situation, if frequent bribe paying reduces the detrimental effect on trade of long waiting times (time is costly, see Hummels, 2001 and Djankov et al., 2006) or low quality of customs. The variables constituting the interaction term are excluded from the regression in order to avoid multicollinearity.

The interaction variables consist of the product of the quality of institutions times an index of the frequency of bribe paying. The latter has been defined as 7 (the index's highest score) mines the index of frequency of bribe paying. In this manner, an increase in the interaction term reflects worse institutions or more bribe paying. The coefficient of the interaction between waiting time at the border and bribery is negative and highly significant (Table 4.3, column 4), signalling that the combination of bad institutions and bribery are detrimental for international trade. The other interaction variable is the product of the frequency of payments and quality of customs. Its coefficient is positive. The effect is always insignificant for the importing country and marginally significant for the exporting one (Table 4.3, column 5). The effect of this interaction variable is positive, whereas that of the quality of customs in the importing country is negative (Table 4.3, column 3). This difference in result suggests that bribery compensates for the bad quality of customs in importing countries.

[6] Keep in mind that the higher the score on this variable, the less frequently payments are made. See the Appendix A for more details.

		(1)	(2)	(3)
Corruption in importing country	Good	-0.211	-0.188	-0.196
		(3.15)**	(2.80)**	(2.95)**
		(1.99)	(1.80)	(1.85)
		(3.37)**	(3.10)**	(3.26)**
	Bad	-0208	-0.241	-0.248
		(3.02)**	(3.59)***	(3.71)***
		(2.01)*	(2.35)*	(2.48)*
		(3.18)**	(3.73)***	(3.26)***
Corruption in exporting country	Good	-0.167	-0.156	-0.164
		(2.14)*	(2.00)*	(2.10)*
		(2.33)*	(2.17)*	(2.29)*
		(0.86)	(0.79)	(0.84)
	Bad	-0.108	-0.140	-0.110
		(1.37)	(1.79)	(1.40)
		(1.46)	(1.97)	(1.50)
		(0.56)	(0.72)	(0.58)
N		2644	2644	2644

Table 4.4: Bilateral trade (average 1999 to 2002): bribery corruption at the border under good and bad customs (institutions). In column (1) the division between bad and good institutions is based on the waiting time at the border. One week appears to be the threshold. We present the results for 8 days. In columns (2) and (3) the division between good and bad institutions is based on the score of the quality of customs. The range appears to be between a score of 2.9 and 3.1. Column (2) presents the results for 2.9 and column (3) for 3.1. In each column, we first present the estimated coefficient. Below the coefficient, we present between brackets the absolute value of the t-statistic for the regression with respectively no correction for clustering, correction for clustering by importing country and correction for clustering by exporting country. Standard errors are corrected for heteroscedasticity by White's procedure. ***: significant at the 99% confidence level **: significant at the 95% confidence level, *: significant at the 90% confidence level.

One could argue that the latter results are found because the sample consists of countries with both (very) good and bad institutions. An argument could be made that bribe-paying facilitates trade only in those countries that have bad institutions. We therefore make a distinction between countries with bad and those with good institutions. The division is based on the countries' scores on waiting time at the border and quality of customs, respectively. In order to avoid an arbitrarily drawn distinction between bad and good institutions, we consider break points in the range of plus and minus one standard deviation from each of the two variables' means. For waiting time at the border, significant coefficients are only found when the threshold equals 8 days (Table 4.4, column 1). For the importing country, the difference between the coefficient for countries with bad and those with good institutions is negligible. Both coefficients suggest a facilitating effect, although the coefficient of bad institutions is always significant. For all other estimation methods and break-points considered no significant coefficients are found. So, this forms very weak evidence of bribe paying acting as a compensation for bad institutions.

When the quality of customs is used as an indicator of institutions' quality, the difference in effects between good and bad institutions appears to be for scores between 2.9 and 3.1. Bribe paying enhances international trade both for countries with bad and those with good institutions (Table 4.4, columns 2 and 3). This facilitating function is the largest and the most significant for importing countries with bad institutions. The influence under bad institutions remains significant if we correct for clustering by importing country. For the exporting country the influence of bribing is mostly insignificant.

It is interesting to compare our results with those of Tavares (2007), who considers the impact of countries' trade liberalization reforms in the 1980's and 1990's on corruption. Many countries with low quality of customs have liberalized trade recently. This should not be surprising: one would expect the quality of customs to improve after prolonged periods of exposure to international trade. What this tells us then is that bribery facilitates imports during the transition period.

In sum, the regressions in which countries with bad institutions are distinguished from those with good institutions provide evidence that bribes facilitate imports in countries with bad institutions. No systematic significant effect is found for the exporting country.

4.6 The uncertainty of corruption and international trade

Finally, we investigate whether it matters that corruption is chaotic: traders are uncertain about whom to bribe (and how often) and the service delivered. The first indicator we use is the score based on the answers to the question whether firms usually know in advance about how much this 'additional payment' is. The higher the score, the less business people know in advance about this amount. We take this as an indicator of unpredictability. Unexpectedly, the effect appears to be significantly positive both for the importing and exporting country (Table 4.5, column 1). This suggests that either uncertainty enhances trade, which is unlikely, or that the respondents interpret this question as asking for bribe paying. A low score would than signal a worse situation in that one always has to pay bribes, whereas a high score reflects the situation where one sometimes has to bribe officials. The high correlation coefficient of 0.83 of this variable with the scores on whether irregular additional payments are required, provides evidence for the hypothesis that both refer to the same phenomenon. Given these confusing results, we estimated

	(1)	(2)	(3)	(4)	(5)
Corruption in importing country	0.329	0.286	-0.068	-0.084	0.354
	(5.81)***	(4.98)***	(0.99)	(1.07)	(7.19)***
	(2.71)**	(1.87)	(0.51)	(0.58)	(3.53)***
	(3.65)***	(5.80)***	(0.84)	(0.84)	(4.72)***
Corruption in exporting country	0.697	0.025	0.321	0.354	0.661
	(11.57)***	(0.39)	(4.35)***	(4.76)***	(13.07)***
	(7.98)***	(0.50)	(4.25)***	(3.99)***	(13.33)***
	(4.44)***	(0.12)	(1.64)	(1.60)	(5.18)**
N	2028	5831	3142	2313	1932
Sample restricted to the 1932 observations of column (5)					
Corruption in importing country	0.334	0.285	-0.00	-0.02	
	(5.66)***	(2.71)**	(0.0)	(0.18)	
	(2.63)*	(1.27)	(0.0)	(0.10)	
	(3.64)***	(3.23)**	(0.0)	(0.15)	
Corruption in exporting country	0.780	0.306	0.415	0.458	
	(11.98)***	(2.69)**	(4.30)***	(5.23)***	
	(8.25)***	(2.91)**	(3.98)***	(4.44)***	
	(4.67)***	(0.99)	(1.61)	(1.89)	
N	1932	1770	1892	1910	

Table 4.5: Bilateral trade (average 1999 to 2002): unpredictability of corruption. Columns: (1) it is usually known in advance how much additional payments are required, (2) standard deviation CPI, (3) predictability of laws and regulations, (4) economic predictability, and (5) recourse to other official. In each column, we first present the estimated coefficient. Below the coefficient, we present between brackets the absolute value of the t-statistic for the regression with respectively no correction for clustering, correction for clustering by importing country and correction for clustering by exporting country. Standard errors are corrected for heteroscedasticity by White's procedure. ***: significant at the 99% confidence level **: significant at the 95% confidence level, *: significant at the 90% confidence level.

the effects of other measures of unpredictability.

The second indicator for the arbitrariness of corruption is the standard deviation of the Corruption Perceptions Index (CPI). This is a valid indicator for the arbitrariness of corruption if the variance of the CPI reflects the uncertainty among respondents about the true spread of bribes. However, this variance might also reflect heterogeneous conditions in a country or judgment difficulties on the side of respondents, so that the results should be interpreted with care. It only has a significant sign for the importing country, when we do not correct for clustering by importer (Table 4.5, column 2).

The third and fourth indicators of predictability are from the Predictability module of WBES. The first one asks for economic predictability and refers to scores on the answers to the question whether business people regularly have to cope with unexpected changes in economic and financial policies which materially affect their business. The other one refers to the predictability of laws and regulation. Both indices are scaled such that higher scores reflect less predictability. In importing countries the unpredictability of both laws and regulation and economic and financial policies do not affect the volume of imports (Table 4.5, columns 3 and 4). For exporting countries the unpredictability suggests an increase in exports, although its significance disappears when we correct for clustering by exporter. This provides weak evidence for the hypothesis that the unpredictability of domestic policies stimulates firms to enter foreign markets. Regressions with firm level data, however, reveal a negative impact of unpredictability on the percentage exported (see Appendix B, Table 4.10).

Theoretically, bribery occurs more frequently if businesspersons have lower effective recourse through government channels or managerial superiors (Herrera et al., 2003). In order to test this, we include in the regression the degree to which businesspersons say they have recourse to other officials, so that they may avoid corruption. The higher the score the less this possibility exits. This indicator is significant and robust to the various ways of correcting clustering (Table 4.5, column 5). However, unexpectedly its coefficient has a positive sign; the less scope for turning to another official, the higher exports and imports are. No significant coefficients are found for the firm level regressions (Table 4.10).

4.7 Concluding remarks

We have used indicators of the quality of customs and bribe paying at the border to investigate the effects of corruption on bilateral trade. The results are compared with those based on indicators of corruption in general. The indicators used refer more to facts and experiences than other indices that often rely on perceptions only. A distinction has been made between corruption in the importing country and in the exporting country. The gravity relations were estimated by Ordinary Least Squares a la Baier – Bergstrand, with correction for clustering by importer and exporter respectively.

Measures of corruption in general suggest that corruption hampers international trade. The results are most robust for the index derived from the WBES and for corruption in the exporting country. Quite different results are obtained when we use indicators of corruption and quality of institutions directly related to international trade. Frequent payments to customs enhance imports. No significant effect for exports is found. Bad institutions – measured by number of days one has to wait at the border – hamper imports. The results for exporting countries are less robust. The results for the quality of customs also suggest the negative effect of bad institutions on international trade, but this result is less robust. The facilitating effect of payments to customs on imports appears to be the largest and most significant in countries with bad quality of customs. Hence, bribing seems to compensate for the detrimental effects of bad institutions in importing countries. We investigated the effect of uncertainty and unpredictability on international trade. For this analysis, we once again had to make use of indicators of unpredictability in general. The results are confusing in that they reveal a positive effect of unpredictability on international trade. In the case of the (un)known amounts to pay, this result is likely to be due to the high correlation with answers on whether one often has to pay additional payments. The unpredictability of economic policies and of laws and regulation has no effect on imports but seems to stimulate exports, although the latter effect is not robust to correction for clustering. Recourse to another official appears to reduce international trade, which is a result opposite to our expectations, unless we suppose that recourse to another official merely results in more claims for bribes, which would happen if corruption were endemic in the government bureaucracy (Kahana and Liu, 2010).

Our analysis shows the importance of using variables directly related to corruption and institutions at the border to investigate the effect of corruption and institutions on international trade. Often the results are opposite to those found for corruption in general. Most robust results are found for waiting time at the border, a variable directly related to experience instead of perceptions. Furthermore, the effects for importing countries differ from those for exporting countries, so that distinguishing between the two is crucial.

Since data on corruption were available for one year only, we were unable to perform a dynamic analysis. Such an analysis might reveal different effects. Busse and Hefeker (2007), for example, find no influence of corruption on foreign direct investments in a cross-section analysis and a negative effect in a dynamic panel analysis.

4.8 Appendix A: Data Sources

The dependent variable is the average of bilateral exports of total commodities for the years 1999 to 2002, measured in dollars, Standard International Trade Classification, Revision 1. Source: COMTRADE database, issued by the United Nations Statistics Division. The countries' Gross Domestic Product (per capita) for the years 1999 to 2002 is in constant 1995 dollars; Source: World Bank, World Development Indicators.

The data on bilateral characteristics such as distance and the dummy variables of a common border, a common language, common coloniser (after 1945), and colonial link are from Centre d'Etudes Prospectives et d'Informations Internationales (CEPII). This data set draws on previous sources developed by Haveman and Henderson.[7] Distance is measured as the great circle distance between the most important cities or agglomerations (in terms of population) between a pair of countries in thousand kilometres.[8]

[7] Specifically, we deleted some countries, and added others. We also adjusted the common language dummy for some countries (e.g. Denmark), because we only wanted matching first languages.

[8] See http://www.cepii.fr/distance/noticedist_en.pdf for the methodology and the technical description. Date accessed 27/10/2010.

The measures of corruption relate to corruption in general and to corruption at the border. Unless indicated otherwise these measures are from the World Business Environment Survey (WBES), © The World Bank Group.[9] We use for each country the unweighted average of the answers to the following questions. Measures of corruption are:

• country scores on the Corruption Perceptions Index 2002, ranging from 0 (highly corrupt) to 10 (almost clean); Source: Transparency International.[10]

• country scores on control of corruption in the year 2002, ranging from about -2.5 to 2.5, with higher values corresponding to better governance outcomes. Source: The Governance Matters III indicators as published in Kaufmann, Kraay and Mastruzzi (2003).[11]

The remaining indicators are from the WBES. The first four are from its Section IV Bureaucratic Red Tape, and the last two questions are from the module III Predictability.

• *corruption - common for firms to pay additional payments*, answers to the question: “It is common for firms in my line of business to have to pay some irregular ‘additional payments’ to get things done. This is true…”. Scores range from 1 (always) to 6 (never);

• *corruption - known amount of additional payment*, answers to the question: “Firms in my line of business usually know in advance about how much this ‘additional payment’ is. This is true…” Scores range from 1 (always) to 6 (never);

• *corruption - recourse to another government official*, answers to the question: “If a government agent acts against the rules I can usually go to another official or to his superior and get the correct treatment without recourse to unofficial payments. This is true…”. Scores range from 1 (always) to 6 (never);

• *corruption - frequency of payments to customs authorities*, answers to the question: “Do firms like yours typically need to make extra, unofficial payments to public officials when dealing with customs/imports?” Scores range from 1 (always) to 6 (never)[12];

• *number of days to import goods*, answers to the question: “If you import, how long does it typically take from the time your goods arrive in their point of entry (e.g. port, airport) until the time you can claim them from customs?” Scores are in days[13];

• *quality of customs*, answers to the question: “Please rate the overall quality and efficiency of services delivered by the following public agencies or services – Customs Service/Agency”. Scores range from 1 (very good) to 6 (very bad);

• *predictability of law and regulations*, answers on the question: ”Do you regularly have to cope with unexpected changes in rules, laws or regulations which materially affect your business?” Changes

[9] Research by Hellman et al. (2000) found no systematic biases in the data. The data can be obtained from The World Business Environment Survey (WBES) 2000, The World Bank Group, http://info.worldbank.org/governance/wbes/, Date accessed 27/10/2010.

[10] A detailed description of the methodology can be obtained from Corruption Perception Index 2002, Transparency International, http://www.transparency.org/policy_research/surveys_indices/cpi/2002, Data accessed 27/10/2010. We deleted Moldova and Taiwan, because these countries were not available in the UN COMTRADE database.

[11] The source of this indicator is the Governance Matters III indicators, Kaufmann, Kraay and Mastruzzi (2003), Governance Matters III: Governance Indicators for 1996-2002, at http://www.worldbank.org/wbi/governance/govdata2002, Date Accessed 27/10/2010.

[12] All scores with values “0” or greater than 6 were transformed to “6” (i.e. “never”).

[13] All scores with the value “97” (days) are missing values and were deleted from the data set.

	One S.D. < Mean	Mean	One S.D. > Mean
Control of corruption	Libya	Suriname	Oman
Corruption Perceptions Index	Bolivia, Cameroon, Ecuador, Haiti	Costa Rica, Jordan, Mauritius, South Korea	Ireland
Frequence of payments	Azerbaijan	Bulgaria	France
Number of days to import	Hungary	Armenia	Ecuador
Quality of customs	El Salvador	Romania	Ukraine
Known amount of payments	El Salvador	Armenia	Malaysia
Predictability of laws and regulation	Pakistan, Trinidad and Tobago	Mexico	Venezuela, Belarus
Predictability of economic policy	Canada, Costa Rica	Thailand	Colombia, Lithuania
Recource to another official	Sweden	Canada	Lithuania

Table 4.6: Some data on corruption variables as illustration: countries at various levels of quality.

in rules, laws and regulations are: (1) completely predictable, .. (6) completely unpredictable.

• *economic predictability*, answers on the question: "Do you regularly have to cope with unexpected changes in economic and financial policies which materially affect your business?" Changes in economic and financial policies are: (1) completely predictable, … (6) completely unpredictable.

4.9 Appendix B: Corruption at the firm level

As mentioned in the main text, some corruption indicators are based on firms' answers on question in the WBES. The individual firms' answers are available, which enables us to investigate whether the relations described in the main text for the macro level are also found when using firm level data. The endogenous variable is the percentage of output exported. Its range is 0 – 100. Consequently, the relations have to be estimated by a Tobit procedure with a lower limit of 0 and an upper limit of 100. Since the firms are from different countries, we correct the standard deviations for clustering. Moreover, an Instrumental Variables (IV) estimator is used. As in Fisman and Svensson (2007), we use as an instrument, the country's mean of the endogenous variable, the corruption index in this case.

We use as explanatory variables the same corruption variables as in the main text. In addition, the following variables are included for controlling for the individual firms' characteristics: the percentage of foreign ownership, the logarithm of the firm's age, the firm's size. Three variables are available for the firm's size: the value of sales, the value of fixed assets and an indicator of the firm's size. For this last variable, we present the results obtained by a Tobit regression with correction for clustering per country. Unless stated otherwise the results are similar for the other two measures of firm size. We also indicate the differences if any between the OLS and the Instrumental Variables approach.

The control variables all have the expected sign and are significant. The percentage of exports is higher when the percentage of foreign ownership increases and when the firm's size increases. It is lower for older (often more traditional) firms. The number of days at the border is the only corruption indicator

	ccur	imcpi	frqpay	nodim	qcus	know	pay	recoff	cpi	lpred	epred
ccur	1										
imcpi	0.95	1									
frqpay	0.54	0.56	1								
nodim	-0.66	-0.65	-0.36	1							
qcus	-0.66	-0.68	-0.45	0.42	1						
know	0.55	0.57	0.38	-0.56	-0.34	1					
pay	0.48	0.51	0.29	-0.52	-0.32	0.83	1				
recoff	0.32	0.28	0.08	-0.36	-0.27	0.38	0.49	1			
cpi	-0.12	0.00	-0.12	-0.04	0.23	0.17	0.05	0.14	1		
lpred	-0.39	-0.33	-0.24	0.24	0.40	0.10	0.19	0.23	0.13	1	
epred	-0.45	-0.39	-0.22	0.26	0.48	0.04	0.08	0.17	0.19	0.93	1

Table 4.7: Correlation matrix. Ccur, control of corruption; imcpi, logarithm of Corruption Perception Index; frqpay, frequency of payments to customs; nodim, logarithm of the number of days goods stay at the border; qcus, quality of customs; know, know in advance about the additional money to be paid ; pay, additional payment required to get things done; recoff, resource to another official, cpi, standard deviation of the corruption perception index; lpred, predictability of laws and regulation; epred, predictability of economic and financial policies.

	(1)	(2)	(3)	(4)
Frequency to pay	-0.938			
	(-0.67)			
Number of days		-0.681***		
		(-5.00)		
Log number of days			0.822	
			(1.14)	
Quality of customs				-1.375
				(-1.16)
Percentage of foreign owner	0.538***	0.249*	0.257*	0.514***
	(4.24)	(2.51)	(2.49)	(4.14)
Firm’s size	33.10**	21.44**	20.17**	32.50**
	(2.68)	(2.77)	(2.67)	(2.84)
Log of firm’s age	-6.621***	-9.973**	-9.849**	-8.470***
	(-3.59)	(-3.02)	(-3.09)	(-4.18)
Constant	-46.57	11.64	9.175	-38.07
	(-1.41)	(0.68)	(0.53)	(-1.23)
Sigma	53.33***	46.97***	47.25***	52.47***
	(7.76)	(10.03)	(10.15)	(8.04)
N	1171	709	709	1024

Table 4.8: The percentage of sales exported (Tobit regression corrected for clustering). t-statistics in parentheses . ***: $p < 0.001$, **: $p < 0.01$, *: $p < 0.05$.

	(1)	(2)
Bribery*number of days	-0.309***	
	(-3.77)	
Bribery*quality of customs		0.192
		(0.79)
Percentage of foreign owner	0.194*	0.423***
	(2.45)	(4.96)
Firm's size	17.45**	26.64**
	(3.17)	(3.29)
Log of firm's age	-6.95***	-5.59**
	(-3.56)	(-3.18)
Constant	11.26	-35.86
	(0.74)	(-1.43)
Sigma	40.28***	44.98***
	(14.52)	(11.14)
N	709	1024

Table 4.9: Interaction between quality of institutions and bribery on the percentage of sales exported (Tobit regression corrected for clustering by country). t-statistics in parentheses. ***: $p < 0.001$, **: $p < 0.01$, *: $p < 0.05$.

that significantly reduces the percentage of exports (Table 4.8). This result also holds if we use sales or assets as a proxy for firms' size. As usual in cross-section regressions, the coefficient increases when using IV. The coefficient of waiting time at the border remains significant when the indicator of firm size is used; it is not significant for assets or sales as indicators of size. In the latter case, the frequency to pay becomes marginally significant.

The interaction between bribery and bad institutions measured by the number of days one waits at the border is significant and negative (Table 4.9, column 1). Since the number of days had already a significant negative effect on exports, this implies that for exports, bribery does compensate the detrimental effects of long waiting times completely. This coefficient and its significance do not change much under IV, when sales or assets measure firms' size. The interaction between quality of customs and bribery is insignificant. This result is unaffected by the use of assets or sales as a proxy for size. Under IV the last coefficient increases by approximately 7 but remains insignificant when the indicator of size is used. When sales or assets represent firms' size, the coefficient's size increases more and becomes significant at the 10 percent level.

The unpredictability of laws and regulations (Table 4.10, column 2) and of the economy (Table 4.10, column 3) both have a significant negative influence on the percentage of sales exported. Under Instrumental Variables estimation, these coefficients do not change much but become insignificant, whereas that of known amount of payments changes sign and becomes significant. These results hold for all three proxies of the firms' size.

	(1)	(2)	(3)	(4)
Known amount	-0.357			
	(-0.31)			
Predictability of laws and regulation		-5.094*		
		(-2.38)		
Predictability of economic policy			5.724***	
			(-3.45)	
Recourse to official				1.264
				(1.33)
Percentage of foreign owner	0.592***	0.419**	0.414**	0.472**
	(3.67)	(2.65)	(2.66)	(2.80)
Firm's size	24.30***	19.15***	19.15***	24.49***
	(4.21)	(3.44)	(3.43)	(4.86)
Log of firms' age	-10.13***	-7.447***	-7.581***	-7.408***
	(-3.50)	(-4.15)	(-4.20)	(-3.75)
Constant	-18.83	9.386	12.18	-26.72
	(-0.78)	(0.55)	(0.64)	(-1.20)
Sigma	53.16***	47.63***	47.55***	50.43***
	(6.36)	(7.37)	(7.24)	(6.73)
N	654	899	899	755

Table 4.10: The effect of corruption's (un)predictability on the percentage of sales exported (Tobit regression corrected for clustering by country). t-statistics in parentheses. ***: $p < 0.001$, **: $p < 0.01$, *: $p < 0.05$.

4.10 Appendix C: List of countries.

Group 1: Countries in CPI, concur and WBES

Albania, Argentina, Azerbaijan, Bangladesh, Belarus, Bolivia, Botswana, Brazil, Bulgaria, Cameroon, Canada, Chile China, Colombia, Costa Rica, Cote d'Ivoire, Croatia, Czech Republic, Dominican Republic, Ecuador, Egypt, El Salvador, Estonia, Ethiopia, France, Georgia, Germany, Ghana, Guatemala, Haiti Honduras, Hungary, India, Indonesia, Italy, Kazakhstan, Kenya, Lithuania, Madagascar, Malawi, Malaysia, Mexico, Namibia, Nicaragua, Nigeria, Pakistan, Panama, Peru, Philippines, Poland, Portugal, Romania, Russia, Senegal, Singapore, Slovakia, Slovenia, South Africa, Spain, Sweden, Tanzania, Thailand, Trinidad and Tobago, Tunisia, Turkey, Ukraine, United Kingdom, United States, Uruguay, Uzbekistan, Venezuela, Zambia, Zimbabwe.

Group 2: Countries in concur

Afghanistan, Algeria, Andorra, Antigua and Barbuda, Bahamas, Bahrain, Barbados, Benin, Bermuda, Bhutan, Brunei, Burkina Faso, Burundi, Cape Verde, Central African Republic, Chad, Comoros, Congo, Cuba, Cyprus, Dem. Rep. of the Congo, Djibouti, Dominica, East Timor, Equatorial Guinea, Eritrea, Fiji, Gabon, Gambia, Grenada, Guinea, Guinea-Bissau, Guyana, Iran, Iraq, Kiribati, Kuwait, Laos, Lebanon, Lesotho, Liberia, Libya, Liechtenstein, Macao, Macedonia, Maldives, Mali, Malta, Marshall Islands, Martinique, Mauritania, Micronesia, Mongolia, Mozambique, Nepal, Niger, North Korea, Oman, Papua New Guinea, Puerto Rico, Qatar, Rwanda, Samoa, Sao Tome and Principe, Saudi Arabia, Serbia and

Montenegro, Seychelles, Sierra Leone, Somalia, St. Kitts and Nevis, St. Lucia, St. Vincent and the Grenadines, Sudan, Suriname, Swaziland, Syria, Tajikistan, Togo, Tonga, Turkmenistan, Vanuatu, Yemen.

Group 3: Countries in CPI and concur

Angola, Australia, Austria, Belgium, Denmark, Finland, Greece, Hong Kong, Iceland, Ireland, Israel, Jamaica, Japan, Jordan, Latvia, Luxembourg, Mauritius, Morocco, Netherlands, New Zealand, Paraguay, South Korea, Sri Lanka, Switzerland, United Arab Emirates, Vietnam.

Group 4: Countries in WBES and concur

Armenia, Belarus, Belize, Bosnia and Herzegovina, Cambodia, Kyrgyzstan, Moldova, Uganda.

Note: We order countries according to data availability. Group 1 includes countries for which we have data on Concur, CPI and at least one measure of WBES. Group 2 includes countries for which we have data on Concur only. Group 3 includes countries for which we have data on Concur and CPI. Group 4 includes countries for which we have data on Concur and at least one measure of WBES. Concur refers to the control of corruption, CPI refers to Corruption Perceptions Index and WBES refers to our selected indicators from the World Business Environment Survey (See appendix A).

Chapter 5

Can Globalization Outweigh Free-Riding?

5.1 Introduction

The recent growth in the number of bilateral and multilateral free trade agreements and the ongoing pursuit of globally liberalized trade by the WTO and its members implies that policy makers have become more and more restricted in the use of trade policies. Since WTO regulations have led to many obligations with respect to the imposition of trade measures, domestic policy makers might resort to environmental policies in order to achieve domestic policy goals. This presents domestic policy makers with a dilemma over the use of environmental policies: they might resort to environmental policies in order to achieve domestic policy goals. These objectives often evolve around raising competitiveness of domestic firms in global markets, i.e. profit shifting, and/or limiting market-access of foreign firms to domestic markets. This has led to growing concerns that trade liberalization will intensify regulatory competition in environmental policies between countries, thereby invoking a race to the bottom. Such a race to the bottom implies that all governments reduce their environmental policies downwards (see Ederington (2010)). In this respect, trade liberalization could have disastrous consequences for global environmental quality.

The rationale for a race to the bottom in this institutional context sounds convincing, however, it is not a necessary outcome. In fact, some have argued that there might be a race to the top instead. If the elasticity of demand for domestic products on world markets is sufficiently low, a certain fraction of the costs of environmental policy can be passed through to foreigners via higher prices. This incentive is stronger the larger the portion of trade that crosses national borders. As McAusland and Millimet (2010) explain, international trade might actually be more beneficial for the environment than intranational trade. This brings us to the first main question of this chapter: *is it possible that increased openness to international trade leads to efficient environmental policies*? Of course, there is a substantial amount of theoretical research that tries to determine whether trade results in environmental degradation. The usual method of analysis here is to compare levels of pollution under autarky and under international trade, conditional on various forms of environmental policy. In our opinion too much emphasis has been put on this approach while other, equally relevant aspects of globalization have received fairly little attention of have been ignored altogether.

In this chapter we consider three different, but related aspects of globalization. These three concepts can be defined as (i) the degree trade openness, as measured by trade intensity and the volume of trade relative to GDP, (ii) the degree of vertical integration across countries in the context of trade in intermediate goods and (iii) the degree of international factor ownership. The latter two international interdependencies are crucial to the ongoing process of globalization, and very important from an empirical point of view, but have often been ignored in applied work. We will define these concepts more explicitly when presenting our model and when we review the literature. This brings us to the second main question of this chapter, closely related to the first one: *Can these interdependencies outweigh free-riding between nation states in the case of transboundary pollution*?

To investigate these questions, we employ a multi-country trade model with two-way trade in dirty intermediate goods. Each country produces a unique set of intermediates under constant returns to scale which allows policy makers to export part of the costs of environmental policy onto their trading partners. From an empirical point of view our analysis does justice to the fact that over the last few decades the growth in international trade has to a large extent been driven by the growth of trade in intermediate products. Another relevant feature is that in many cases these intermediate goods are not only used as inputs for the production of final goods but they are also used as inputs to the production of intermediate goods. To this end our model incorporates a simple input-output structure of production.

The rest of this chapter is set up as follows. In the next section, we contrast our approach with the existing literature and preview some of our results. In section 3 we discuss the characteristics of our trade model. In section 4 we discuss the relationship between environmental policy, terms-of-trade effects and TFP effects, which forms the core of our analysis. Section 5 then compares the social optimum to the non-cooperative Nash equilibrium. We analyze various properties of the Nash equilibrium and carefully spell out its implications for global environmental quality. We then move on to discuss the effects of strengthening the international input-output structure and consider the effects of decentralization on global welfare and green welfare. In the last section we complement the input-output structure with international factor ownership, an economic interdependency that is often associated with trade in intermediate inputs. The last section concludes.

5.2 Literature Overview

In this section we relate our analysis and its questions to the existing literature. The environmental consequences of trade in intermediate goods are relatively unexplored in the literature on trade and the environment. Some important exceptions are Benarroch and Weder (2006), McAusland (2005) and Hamilton and Requate (2004). Hamilton and Requate (2004) examine strategic environmental policy in a partial equilibrium model where exports are produced in a vertically related industry structure with a downstream and upstream sector. They conclude that if vertical contracts are allowed, the optimal environmental tax that should be levied on the polluting input is actually a Pigouvian tax. Our work is similar in the sense that we are interested in non-cooperative environmental policy in the presence of a vertical production structure. Unlike their paper, we consider international vertical structures instead of intranational vertical structures. Other important differences are our focus on general equilibrium, the generalization to a large number of countries, the role of decentralization versus centralization and the input-output structure of production. Similar to our analysis, dirty intermediate goods are a central element of McAusland (2005), but her focus is far more specific, i.e. environmental regulation as export promotion with an industry that is subject to economies of scale. Our focus is on non-cooperative policies in a vertically integrated world economy instead of unilateral policies for a small open economy. Benarroch and Weder (2006) consider a two-country model of trade in intermediate goods with monopolistic competition. They only consider pollution from final goods and abstract from optimal environmental policies.

There is some recognition that increased openness can indeed lead to stricter environmental regulation via negative price spillovers. Pflüger (2001), in a model of monopolistic competition with an exogenous number of consumer varieties, finds that openness leads to stricter environmental regulation via consumer price spillovers. Haupt (2006), using a model of monopolistic competition with an endogenous number of varieties, finds that non-cooperative governments might implement inefficiently stringent standards in case of local production externalities. Similarly, in a model of oligopoly Duval and Hamilton (2002) find that a net exporting country might select an inefficiently high environmental tax since under certain conditions the rent-shifting motive (see Kennedy (1994)) is outweighed by the motive to export the tax burden to foreign consumers (tax-exporting motive).

From a regulatory point of view, one can argue that international trade decouples the costs of environmental policy from the benefits of environmental policy when compared to a situation of autarky or interregional trade. This is because trade affects the costs, not the benefits, of environmental regulation if a certain fraction of domestically produced goods is exported. Two conditions are crucial for our argument. First, when determining the stringency of environmental regulation, the domestic regulator only internalizes the costs of environmental policy in as far they are borne by domestic producers and consumers. Second, export demand should be sufficiently inelastic such that the burden of environmental regulation falls on importers as well. Provided these conditions are met, the costs of environmental policy will fall with trade intensity. Therefore, stringent environmental policy will be easier for smaller than for large countries because ceteris paribus trade intensity is smaller for the latter. This beneficial aspect of policymaking in open economies is coined "regulatory decoupling" by McAusland and Millimet (2010). We generalize the beforementioned contribution by relating regulatory decoupling directly to a terms-of-trade prisoner's dilemma and by examining the consequences for (green) welfare. The terms-of-trade dilemma here is different from conventional wisdom: small, not large countries have a greater incentive to abuse trade policy (or environmental policy) to manipulate their terms-of-trade. More importantly, we are able to connect the tax-exporting motive to the three different aspects of globalization.

Ogawa and Wildasin (2009) find that under certain conditions decentralized policymaking can actually lead to efficient outcomes when pollution is transboundary. In a sense, our work has a similar modus operandi to the literature on tax competition by relating the degree of decentralization (via trade intensity) to regulatory incentives, but our model set-up is more closely related to the literature on trade and the environment with emphasis on terms-of-trade effects and abatement possibilities.

With respect to our model structure, there exists a substantial literature on vertical integration, intermediate goods and international trade. Yi (2003) uses a two-country dynamic Ricardian trade model to explain how trading (un)processed intermediate goods back and forth between countries can lead to magnification of the impact of tariffs on final goods prices. We will explain later how this intermediate goods multiplier has important consequences for the effects of environmental policy. Now, suppose that in order to produce a final good one has to complete a sequence of production steps, involving different tasks and/or intermediate goods at each stage. In addition, suppose that these stages of production are implemented using long supply chains that stretch out over many different countries. In such a context, two characteristics of a vertically integrated world economy, as in Yi (2003), stand out. First of all, and according to Yi (2003), vertical specialization occurs when countries specialize in certain stages of this production sequence. Second, according to Hummels, Ishi and Yi (2001) vertical specialization occurs when imported intermediate goods are used to produce export goods. We denote these features of the vertically integrated world economy respectively as (i) supply chain specialization and (ii) the double role of intermediate goods as imports and exports in an international input-output structure of production.

Our model takes a simplified approach to the vertically integrated world economy. First, we assume that each country produces a unique set of intermediate goods. In turn, the total set of world intermediates can be combined to form a composite intermediate good. In this way we capture supply chain specialization. Second, we assume countries import the composite intermediate good to produce tradable intermediate goods, thereby capturing the input-output structure.

Our findings show that under some circumstances decentralization of environmental policy is actually beneficial for the environment. First, and depending on the specific model parameters, we find that in the case of local pollution (sulfur) the decentralized solution, where trade openness is high, might provide for a higher environmental quality than the social optimum. However, when pollution is fully transboundary the decentralized solution always leads to sub-optimal low environmental standards. Second, it is shown that a strengthening of the degree of vertical integration, via the international input-output structure, mitigates free-riding, reduces the difference between the non-cooperative and cooperative solution and possibly increases the quality of the global environment. Third, similar to vertical integration it is found that a high degree of international factor ownership can mitigate free-riding by increasing the degree to which the costs of environmental policy are borne by foreigners. The implication of these results is that the increasing interconnectedness between countries in manufacturing industries might lead to better environmental outcomes in a world where non-cooperative approaches to environmental policy remain important.

5.3 The Model

The world consists of N countries indexed by $j = 1, 2, .., N$. In each country there are three different sectors, producing (1) tradable intermediate goods, (2) a composite intermediate good and (3) a non-tradable final consumption good. In this respect the production structure is identical to Acemoglu and Ventura (2002). We extend their production structure by assuming that a composite intermediate good is not only used as an input to the final goods sector, but also serves as an input in the production of tradable intermediates.[1]

There exists a continuum of tradable intermediate goods with mass M. We assume that country j produces a unique subset n_j from this set of varieties, with $n_j \cap n_k = \emptyset$ for $\forall j, k$ and $\sum_{j=1}^{N} n_j = M$. Again, we assume symmetry such that $n_j = n = \frac{M}{N}$. The assumption that each country produces a unique set of intermediates is simplifying, but captures the idea of supply chain specialization which is one of the critical features of the vertically integrated economy model.

There is only one (primary) factor of production, labor L, that is supplied inelastically and immobile between countries, but is perfectly mobile domestically. Countries engage in two-way trade in intermediate products in order to produce a composite intermediate good. Each country produces a non-tradable final consumption good using labor and the composite intermediate good. The composite intermediate good is also used to produce the tradable intermediates (input-output). We assume that the production process of tradable intermediates is polluting and that abatement can reduce the emission intensity of production. The model is different from most trade models by assuming (i) a large number of symmetric countries, (ii) trade in intermediate goods, (iii) an input-output structure and (iv) emissions from the production of intermediate goods. Assumptions (ii)-(iv) capture our focus on a vertically integrated world economy whereas the assumption of symmetric countries under (i) is adopted because it simplifies the analysis considerably.

5.3.1 Welfare and Consumption

The size of the world population equals L^w. We assume that each individual supplies one unit of labor and that all countries are identical in terms of population size. Under full employment total effective labor supply in each country then equals $\frac{L^w}{N} \equiv L$. Per capita welfare u in country j is determined by consumption and pollution in the following manner:

$$u(c_j, Z_j) = \frac{{c_j}^{1-\sigma}}{1-\sigma} - \eta Z_j \ , \ \sigma > 0 \tag{5.1}$$

where $c_j \equiv C_j/L$ is per-capita consumption of the aggregate consumption good in country j and Z_j is the total pollution flow experienced by citizens in country j. Pollution emitted and pollution experienced by a particular country are not necessarily equal due to spillovers between countries. Let ϕ_{ij} denote the fraction of pollution emitted by country i that spills over to country j. Then pollution experienced by country j is defined as $Z_j = n\left[z_j + \sum_{i \neq j} \phi_{ij} z_i\right]$ where nz_i is pollution generated by production of intermediate goods in country i. With respect to the damages obtained from pollution, we assume that the marginal damage from pollution η is constant. In what follows we will also assume that the spillovers between countries are pairwise symmetric and equal across all country pairs, that is, $\phi_{ij} = \phi_{ji} = \phi$ for all i, j where $i \neq j$. The special cases of $\phi = 0$ and $\phi = 1$ are used to denote, respectively, the degree of spillovers associated with local pollutants (e.g., sulfur) and global pollutants (e.g., carbon).

[1] In this sense the model is similar to Rodriguez-Clare (2007) and Ramondo & Rodriguez-Clare (2010) by assuming an international input-output structure.

5.3.2 Production of Intermediate Goods

The production of tradable intermediate goods requires the input of labor and a composite intermediate good. This last assumption captures the idea that a vertically integrated world economy is characterized by an (international) input-output structure. Under constant returns to scale and imposing a Cobb-Douglas functional form, the production function of a typical tradable intermediate good in country j is given by

$$y_j = (1-\theta_j)(l_{jy})^{\beta}(x_{jy})^{1-\beta} \tag{5.2}$$

where y_j refers to net output, x_{jy} represents the input of the composite tradable intermediate good in the production of a typical intermediate in country j and l_{jy} is the amount of labor employed in the production of a typical variety in country j. With each country producing n intermediates, which are produced with identical technologies (see 5.2), we can define $X_{jy} \equiv nx_{jy}$ and $L_{jy} \equiv nl_{jy}$ as the total input of the composite intermediate good and labor in the production of tradable intermediate goods respectively.

The production of one unit of *net* output generates $e(\theta_j)$ units of pollution, where θ_j is the fraction of gross output of the intermediate good used for abatement in country j.[1] So $(1-\theta_j)$ in (5.2) is the ratio of net output over gross output. Following Copeland and Taylor (2003) we assume a simple iso-elastic specification for the emission intensity, $e(\theta_j) \equiv (1-\theta_j)^{\frac{1-\alpha}{\alpha}}$ with $0 < \alpha < 1$. Total emissions z_j of a typical variety in country then equal:

$$z_j = e(\theta_j)y_j \tag{5.3}$$

A change in θ_j will now affect z_j in three different ways: once directly through e_j, once directly via the reduction in net output y_j and indirectly via the aggregate intermediate good term $(x_{jy})^{1-\beta}$. Alternatively, one might write total pollution of a typical variety in country j as $z_j = (1-\theta_j)^{\frac{1}{\alpha}}(l_{jy})^{\beta}(x_{jy})^{1-\beta}$, where $(1-\theta_j)^{\frac{1}{\alpha}}$ represents the emission intensity per unit of gross output. We assume the government is able to indirectly control the intensity of abatement θ_j by imposing an emission standard $\overline{s}_j = e(\overline{\theta}_j)$ (firm standard), where $\overline{\theta_j}$ is uniquely determined by $\overline{\theta}_j = e^{-1}(\overline{s}_j)$. An increase in θ_j works as an increase in the net unit-input requirement. The emission intensity per unit of output is strictly decreasing in the production standard, that is, $e'(\theta_j) < 0$. In the remaining of this chapter we will always refer to θ_j when discussing the stringency of environmental policy in country j.

The composite intermediate good is produced under constant returns to scale with a roundabout production technology requiring all available intermediate goods, which are imported from world markets. Total production of the composite intermediate good X_j follows a constant elasticity of substitution

[1]The assumption that dirty sectors use a fraction of their own output to abate pollution is common in the literature on trade and the environment. A notable expection is Greaker & Rosenknut (2008). Greaker & Rosenknut (2008) introduce a seperate upstream pollution abatement sector in a partial equilibrium trade model.

(CES) function,

$$X_j = (\sum_{i=1}^{N} n y_{ij}^{\frac{\varepsilon-1}{\varepsilon}})^{\frac{\varepsilon}{\varepsilon-1}} \tag{5.4}$$

where y_{ij} is the input of a typical intermediate good from country i in country j, which represents an import in case $i \neq j$. The parameter ε is the elasticity of substitution between tradable intermediates. It also represents the price elasticity of foreign demand for the country's products and Acemoglu and Ventura (2002) interpret the inverse of this elasticity as a measure of the degree of specialization.

Markets for tradable intermediate goods are characterized by a large number of producers and a large number of buyers from the final goods sector (and the composite intermediate goods sector), and are therefore subject to perfect competition. Perfect competition and constant returns to scale together imply that unit cost pricing prevails:

$$p_j = \frac{1}{\psi}\frac{1}{1-\theta_j}(w_j)^{\beta}(P_X)^{1-\beta} \tag{5.5}$$

where $\psi \equiv \beta^{\beta}(1-\beta)^{1-\beta}$, w_j represents the domestic wage rate and P_X is the price of the composite intermediate good. Profit maximization by producers of the composite intermediate good results in the following price P_X which due to free trade is independent of j:

$$P_X = [\sum_{i=1}^{N} n(p_i)^{1-\varepsilon}]^{\frac{1}{1-\varepsilon}} \tag{5.6}$$

As can be seen from (5.2) and (5.5), a direct consequence of a lower emission standard θ is a decrease in "total factor productivity" (Hicks neutral technical change) and an increase in the price of net output.

5.3.3 Production of the Final Good

The non-tradable consumption good is produced with (i) the composite intermediate good and (ii) labor. The final good production function reads:

$$C_j = \chi(L_{jC})^{1-\tau}(X_{jC})^{\tau} \tag{5.7}$$

where C_j is the output of the consumption good, X_{jC} is the input of the aggregate intermediate good, L_{jC} is the input of labor in the production of the consumption good and $\chi \equiv \tau^{\tau}(1-\tau)^{1-\tau}$ represents a parameter used for normalization.

With perfectly competitive markets the price of the final good is given by:

$$p_{jC} = (w_j)^{1-\tau}(P_X)^{\tau} \tag{5.8}$$

Market clearing for the composite intermediate good in each country requires $X_j = X_{jC} + X_{jy}$. Next, we turn to solve for factor market equilibrium from the balanced trade condition.

5.3.4 Global Environmental Quality

To derive total pollution emitted and "received" in a given country, we use the definition of pollution $Z_j = nz_j + \phi n \sum_{i \neq j} z_i$, and substitute for total pollution per variety z_j from (5.3). This leads to the following specification for total pollution:

$$Z_j = n \left[e(\theta_j)(1-\theta_j)(l_{jy})^{\beta}(x_{jy})^{1-\beta} + \phi \sum_{i \neq j} e(\theta_i)(1-\theta_i)(l_{iy})^{\beta}(x_{iy})^{1-\beta} \right] \tag{5.9}$$

Total pollution depends on environmental policy at home and abroad and the inputs of labor and the composite intermediate good in the production of intermediate goods. Once we have solved for the market equilibrium of the model, we will return to an in-depth analysis of (5.9), where we will take into account the endogeneity of the various inputs. As we will explain, the input-output (IO) structure of our model is of particular interest here.

5.3.5 Market Equilibrium and Trade Balance

In equilibrium the sum of labor employed in the production of tradable intermediates L_{jy} and the non-tradable consumption good L_{jC} should equate the supply of labor:

$$L = L_{jy} + L_{jC} \tag{5.10}$$

Let us define E as world expenditures on intermediates. Demand for each tradable intermediate q_j is of the constant elasticity form,

$$q_j = (p_j)^{-\varepsilon} P_X^{\varepsilon-1} E = (p_j)^{-\varepsilon} E \tag{5.11}$$

The second equality in (5.11) follows after taking P_X as the numeraire. Next, we examine in more detail world expenditures on intermediates. To this end, let us define nominal income in country j as $I_j = w_j L$. Then in all countries final goods producers spend a fraction τ of total costs on intermediates and intermediate goods producers also spend a fraction $1-\beta$ of total costs on the aggregate intermediate good such that $E = \tau I^w + (1-\beta)(\sum_{j=1}^{j=N} np_jq_j)$ where $I^w \equiv \sum_{j=1}^{j=N} I_j$ represents world income. Market equilibrium in the final goods market requires that in each country consumption expenditures equal nominal income, that is, $p_{jC}C_j = I_j$.

Next, we want to rewrite (5.11) in order to obtain the balanced trade condition. In the appendix we display two alternative methods to derive this condition. Let use the abbreviations IM_j and EX_j to refer to imports and exports of intermediate goods by country j. With n intermediate produced by each country and a total number of $N-1$ trading partners, imports and exports are defined as:

$$IM_j = n(p_1y_{1j} + p_2y_{2j} + ... + p_{j-1}y_{j-1,j} + p_{j+1}y_{j+1,j} + ... + p_Ny_{Nj}) \tag{5.12}$$

$$EX_j = n(p_jy_{j1} + p_jy_{j2} + ... + p_jy_{j,j-1} + p_jy_{j,j+1} + ... + p_jy_{jN}) \tag{5.13}$$

Using these definitions of imports and exports (5.12)-(5.13) we can show that $IM_j = \frac{\tau}{\beta} I_j (1 - \frac{I_j}{I^w})$ and $EX_j = np_j^{1-\varepsilon} \frac{\tau}{\beta}(1 - \frac{I_j}{I^w}) I^w$, where the import ratio or export ratio $\frac{IM_j}{I_j} = \frac{EX_j}{I_j} = \frac{\tau}{\beta}(1 - \frac{I_j}{I^w})$ is decreasing in relative income $\frac{I_j}{I^w}$. Equating imports and exports then leads to the balanced trade condition:

$$I_j = n(p_j)^{1-\varepsilon} I^w \tag{5.14}$$

where we divided by $\frac{IM_j}{I_j}$ on both side of the equations. Thus, the left-hand side and right-hand side of (5.14) represent respectively imports and exports divided by the import ratio. Under balanced trade the import ratio is half the trade intensity, which equals $\upsilon_j \equiv \frac{EX_j + IM_j}{I_j} = 2\frac{\tau}{\beta}(1 - \frac{I_j}{I^w})$. With symmetric countries it then follows immediately that $\upsilon = 2\frac{N-1}{N}\frac{\tau}{\beta}$. Acemoglu and Ventura (2002) obtain $\upsilon = 2\tau$, which can be obtained as a special case in our model when $\beta = 1$ (no IO structure) and $\lim N \to \infty$[2].

5.4 Environmental Policy, Terms-of-Trade and IO-linkages

The division of the world into N symmetric countries allows us to define N as the 'degree of decentralization' or, alternatively, define $1/N$ as 'the degree of centralization. The degree of decentralization under symmetry ranges from 1 to ∞, which corresponds respectively to a situation of autarky ($N = 1$) and the small open economy case ($N \longrightarrow \infty$). In what follows we will often refer to small (large) countries when analyzing a situation where N is a relatively large (small) number, such that population size per country $\frac{L^w}{N}$ is relatively small (large). Thus, decentralization refers to a world where the number of countries N is large, population size per country is small and trade intensity $\frac{\tau}{\beta}\frac{N-1}{N}$ per country is high (and converges to $\frac{\tau}{\beta}$ in the small open economy case). Next, we analyze the effects of a unilateral marginal change in domestic environmental policy on wages and prices. The results obtained here will prove to be useful when deriving the non-cooperative Nash equilibrium.

We use subscript A to denote variables of the country that marginally changes environmental policy and we use subscript B to denote all other countries. Ex-ante countries are symmetric so we can write world income as $I^w = I_A + (N-1)I_B = w_A L + (N-1)w_B L$. From the point of view of country A all other countries are identical since they do not change their environmental policies, hence the grouping of other countries under B. Analogously with the definitions related to income, prices of intermediate goods in country A and the other countries are given by $p_A = \frac{1}{\psi}\frac{1}{1-\theta_A}(w_A)^\beta$ and $p_B = \frac{1}{\psi}\frac{1}{1-\theta_B}(w_B)^\beta$ respectively. Substitution of these equations into (5.6) and (5.14) gives us the following set of two equations in $\{w_A, w_B, \theta_A, \theta_B\}$:

$$1 = n\left(\frac{w_A{}^\beta}{1-\theta_A}\right)^{1-\varepsilon} + (N-1)n\left(\frac{w_B{}^\beta}{1-\theta_B}\right)^{1-\varepsilon} \tag{5.15}$$

$$w_A L = n\left(\frac{w_A{}^\beta}{1-\theta_A}\right)^{1-\varepsilon} [w_A L + (N-1)w_B L] \tag{5.16}$$

To analyze the effect of a marginal change in the emission standard on domestic and foreign, we differ-

[2]Similarly, "openness" in our setting equals $\frac{N-1}{N}\frac{\tau}{\beta}$ instead of τ in the model by Acemoglu & Ventura (2002).

entiate the balanced trade equation (5.15) and the price index numeraire equation (5.16) with respect to θ_A, the own wage rate w_A and the foreign wage rates w_B while taking θ_B as constant (see the appendix for a full derivation).

Define $p^0 \equiv \frac{w}{1-\theta}$ as the 'raw price' of the intermediate good when there is no input-output structure, $\beta = 1$, and define the effective price elasticity with respect to environmental policy ε_P as $\varepsilon_P \equiv \lim_{N->\infty}(\frac{dp_A}{d\theta_A}\frac{1-\theta_A}{p_A})$. Using this definition we find, as shown in the appendix, that $\varepsilon_P = \frac{1}{1+\beta(\varepsilon-1)}$. We are now ready to state the first set of results, all related to unilateral changes in environmental policy:

Result 1 *More stringent environmental policy reduces the domestic wage rate,*

$$\frac{dw_j}{d\theta_j} = \left[\underbrace{\frac{1}{\beta}(1-\frac{1}{N})\varepsilon_P}_{ToT} \underbrace{-\frac{1}{\beta}}_{TFP}\right] p^0 = (a-b)p^0 < 0,$$

via a negative TFP effect ($-bp^0 < 0$) *and a positive terms-of-trade effect* ($ap^0 > 0$)*, where* $a \equiv \frac{1}{\beta}(1-\frac{1}{N})\varepsilon_P = \frac{1}{\beta}\frac{N-1}{N}\frac{1}{1+\beta(\varepsilon-1)}$ *and* $b \equiv \frac{1}{\beta}$ *denote respectively the terms-of-trade coefficient and the TFP coefficient. Foreign wages are affected as well via terms-of-trade spillovers,* $\frac{dw_j}{d\theta_j} = -\frac{1}{N-1}ap^0 < 0$*. Prices of intermediate goods increase at home and decrease abroad,* $\frac{dp_j}{d\theta_j} = \beta a\frac{p}{1-\theta} > 0$ *and* $\frac{dp_i}{d\theta_j} = -\beta\frac{1}{N-1}a\frac{p}{1-\theta} < 0$.

Environmental policy affects the return to labor via two different channels. First, there is a TFP effect. We use the term TFP effect, because producers require more inputs to produce one net unit of output if the stringency of environmental policy increases. A higher standard effectively works as a negative TFP effect that lowers the real wage, $\frac{d}{d\theta_j}(\frac{w_j}{p_{jC}}) = \frac{d}{d\theta}(w_j)^\tau = \tau w_j^{\tau-1}\frac{dw_j}{d\theta_j} < 0$, where the negative sign follows directly from result 1. Second, since countries produce a unique set of varieties a part of the costs of environmental policy is translated into higher prices, i.e. positive terms-of-trade effects. The degree to which depends on the elasticity ε_P and the export share of total production ($\frac{N-1}{N}$). The overall impact of these two effects on the wage rate is unambiguously negative since the positive terms-of-trade effect is always overwhelmed by the negative TFP effect (Result 1).

In what way do input-output linkages change the impact of environmental policy on prices of wages? Consider first the case of a large number of small open economies where $N \longrightarrow \infty$. For a small open economy one can ignore changes in foreign wages when determining the impact of a change in θ_A on w_A[3]. The introduction of input-output linkages changes the price elasticity with respect to environmental policy ε_P. Note that for $\beta = 1$ we find that ε_P equals the inverse of the elasticity of demand ε. Therefore one might interpret ε_P as the inverse of the *effective* price elasticity of demand, where effective refers to the indirect changes in demand that results from the interlinkages between production of intermediate goods and the composite intermediate good. To develop the intuition for this result further, note that for $\beta > 0$ and from proposition 1 we observe that the effective price elasticity of demand equals $\varepsilon_D \equiv \frac{1}{\varepsilon_P} = 1+\beta(\varepsilon-1) = \varepsilon-(1-\beta)(\varepsilon-1)$, where $\varepsilon_D < \varepsilon$ as long as $\varepsilon > 1$ and $1 > \beta > 0$. So why is the effective

[3]In practice this means that one can differentiate the balanced trade condition (5.16) with respect to θ_A and w_A, while ignoring the price index equation (5.15).

elasticity of demand smaller in the presence of an input-output structure? Intermediate goods are now even more "important" than before, as evident by the share $1-\beta$ that intermediate good producers spend themselves on other intermediate goods. Thus, with input-output linkages it becomes more difficult to substitute away towards other (local) inputs.

To yield further insights into the large country case, $N \in [1, \infty)$, we can can rearrange $\frac{dw_j}{d\theta_j} = (a-b)p^0$ to highlight the separate effects of N and β:

$$\frac{dw_j}{d\theta_j} = \underbrace{\left(-p^0 + \frac{1}{\varepsilon}p^0\right)\left(1 + \frac{(1-\beta)(\varepsilon-1)}{1+\beta(\varepsilon-1)}\right)}_{\text{small open economy}} - \frac{1}{N}\frac{1}{\beta}\frac{1}{\varepsilon}p^0\left(\frac{\varepsilon}{1+\beta(\varepsilon-1)}\right) \tag{5.17}$$

where the first term on the left-hand side coincides with the effect for a small open economy ($N \to \infty$). In the small open economy the opportunity cost of abatement equals $-p$, that is, the value of foregone output. There is also a terms-of-trade effect that depends on the inverse of the elasticity of demand (see Johnson (1953)). This terms-of-trade effect is strictly proportional to $\frac{1}{\varepsilon}$ when there are no input-output linkages ($\beta = 1$). Large countries have to take into account that they consume a non-negligible portion of domestically produced dirty intermediates, hence the second term on the right-hand side of (5.17). Conclusively, the marginal effect of abatement on the domestic wage rate can be decomposed in a TFP effect (invariant to the degree of centralization) and a terms-of-trade effect which explains that, dependent on country size, countries may export a part of the costs of environmental policy by imposing higher prices. The TFP effect is invariant to the degree of centralization and does not spillover to other countries: result 1 explains that the price spillover from more stringent environmental policy, $\frac{dp_B}{d\theta_A}$, depends on the terms-of-trade coefficient only. Furthermore,

Result 2 *The terms-of-trade effect and the TFP effect are monotonically increasing in the so-called 'intermediate goods multiplier'* $\frac{1}{\beta} \in [0, \infty)$.

A useful interpretation of β can be given by noting that $1/\beta$ represents the intermediate goods multiplier of environmental policy[4]. Intuitively, a higher standard in country A means less production of the intermediate goods produced in A. Ceteris paribus, a lower supply of intermediate goods from A will also lower the total supply of the composite intermediate good. A decrease in the supply of the composite intermediate good then feeds back into the intermediate goods sector and lowers output in this sector. Diminished output of intermediate goods sets in motion a new round with reduced outputs in all sectors. This cycle will repeat itself again and again. The culmination of this cycle is the geometric sequence $1 + (1-\beta) + (1-\beta)^2 + .. = \frac{1}{1-(1-\beta)} = \frac{1}{\beta} > 1$ which holds for any $\beta \in (0, 1]$. We find that both the positive terms-of-trade effect and the negative TFP effect of a higher standard are proportional to the intermediate goods multiplier (Result 2). The explanation for this multiplier follows directly from the previous argument. A stricter emission standard means that more gross output is directed to cleaning-up activities, i.e. abatement, which ceteris paribus leads to a lower supply of the intermediate good. In turn, this lowered supply means less of the aggregate intermediate good as well, which feeds back in the

[4](see Jones (2010) and Rodriguez-Clare (2007))

global production of all intermediate goods and so on.

Result 3 *Terms-of-trade effects of stricter environmental policy are larger when the degree of decentralization increases,* $\frac{da}{dN} = \frac{d}{dN}(\frac{1}{\beta}\frac{N-1}{N}\varepsilon_P) = \frac{1}{\beta}\frac{1}{N^2}\varepsilon_P > 0$. *Stated otherwise, the beneficial terms-of-trade effect that lowers the costs of environmental policy is increasing with the number of countries.*

In the context of traditional trade theories based on (comparative advantage and) homogeneous goods it is well-known that big countries have an incentive to use environmental policy to influence the terms-of-trade. An importer of dirty goods can use an environmental tax that exceeds marginal damage to increase the terms-of-trade vis-à-vis dirty goods exporters. A surprising implication of our set-up is that terms-of-trade effects are actually *smaller* not larger for big countries.[5] To see why, note that the terms-of-trade coefficient, $a = \frac{1}{\beta}\frac{N-1}{N}\varepsilon_P$, is increasing in the number of countries N. This property is not unique to our setting and applies to other models, such as the monopolistic competition model of Krugman (1981), as well. With an increase in trade intensity a greater part of the costs of environmental policy will be borne by foreign consumers via higher product prices (result 3). In other words, if a large part of production is consumed outside the country the incentive for domestic policymakers to impose more stringent environmental policy on domestic firms increases. Then, for any required reduction in the level of emissions, the domestic costs are decreasing with trade intensity.

5.5 Global Pollution and IO-linkages

In this section we aim to clarify the relationship between IO-linkages and global pollution. By rewriting the equation of the composite intermediate good, thereby obtaining a closed-form solution, we get a better understanding of how θ_j affects pollution z_j indirectly via the input of the composite intermediate good.

Define λ_j as a country's consumption share / import share of a typical intermediate good, that is, $\lambda_j \equiv \frac{y_{ij}}{y_i}$ for all i, j. World demand for an intermediate good y_i follows from the balanced trade condition (5.14), $y_i = p_i^{-\varepsilon}\frac{\tau}{\beta}I^w$. Demand for intermediate i by country j is given by $y_{ij} = p_i^{-\varepsilon}X_j = p_i^{-\varepsilon}\frac{\tau}{\beta}I_j$, where the second equality follows from $X_j = X_{jy} + X_{jC} = \frac{1-\beta}{\beta}\tau I_j + \tau I_j = \frac{\tau}{\beta}I_j$. These two demand functions can then be used to derive that

$$\lambda_j = \frac{y_{ij}}{y_i} = \frac{p_i^{-\varepsilon}X_j}{p_i^{-\varepsilon}\frac{\tau}{\beta}I^w} = \frac{I_j}{I^w} \tag{5.18}$$

which tells us that a country's import/consumption share equals relative income. Note that in equilibrium we obtain $I_j = I$ such that $\lambda_j = \frac{I}{NI} = \frac{1}{N}$. The next step is to substitute for $y_{ij} = \lambda_j y_i$ in (5.4) in order to obtain $X_j = nx_j = \lambda_j(\sum_i n y_i^{\frac{\varepsilon-1}{\varepsilon}})^{\frac{\varepsilon}{\varepsilon-1}}$. Then we substitute for all y_i from (5.2) in this result and rearrange:

$$X_j = (\lambda_j)^{\frac{1}{\beta}}(\frac{1-\beta}{n})^{\frac{1-\beta}{\beta}}(G_j)^{\frac{1}{\beta}}l_y \tag{5.19}$$

[5] Remember, when referring to large countries we refer to a world with a small number of countries.

where $G_j \equiv (\sum_i n((1-\theta_i)(\frac{\lambda_i}{\lambda_j})^{1-\beta})^{\frac{\varepsilon-1}{\varepsilon}})^{\frac{\varepsilon}{\varepsilon-1}} = \lambda_j^{\beta-1}(\sum_i n((1-\theta_i)(\lambda_i)^{1-\beta})^{\frac{\varepsilon-1}{\varepsilon}})^{\frac{\varepsilon}{\varepsilon-1}}$. Equation (5.19) determines X_j as a function of import shares and environmental policies. The first term on the right-hand side, $(\lambda_j)^{\frac{1}{\beta}}$, indicates that a large country will produce and consume a more than proportionate share of the composite intermediate good. The composite term G_j can be interpreted as an aggregate, but country-specific technology term which represents an income-weighted average of global environmental policies. A reduction in output due to stricter environmental policies spills over to other countries via this composite technology term and this spillover is naturally increasing in country size.

In turn, (5.19) can be substituted into (5.3) to derive total pollution per variety:

$$z_j = e(\theta_j)(1-\theta_j)(l_y)^\beta \left((\lambda_j)^{\frac{1}{\beta}} (\frac{1-\beta}{n})^{\frac{1-\beta}{\beta}} (G_j)^{\frac{1}{\beta}} l_y \right)^{1-\beta} \tag{5.20}$$

Under full symmetry we can write (5.20) as $z(\theta) = \bar{z}(1-\theta)^\Phi$, where $\bar{z} \equiv z(0) = (\frac{1}{N})^{\frac{1-\beta}{\beta}}(\frac{N}{M}(1-\beta))^{\frac{(1-\beta)^2}{\beta}}\left(M^{\frac{\varepsilon}{\varepsilon-1}}\right)^{\frac{1-\beta}{\beta}} l_y$. Finally, we retrieve world pollution by substitution of (5.20) into (5.9):

$$\begin{aligned} Z_j &= \left[\begin{array}{c} e(\theta_j)(1-\theta_j)(\lambda_j)^{\frac{1-\beta}{\beta}}(G_j)^{\frac{1-\beta}{\beta}} \\ +\phi\left(\sum_{i\neq j} e(\theta_i)(1-\theta_i)(\lambda_i)^{\frac{1-\beta}{\beta}}(G_i)^{\frac{1-\beta}{\beta}}\right) \end{array} \right] (\frac{1-\beta}{n})^{\frac{(1-\beta)^2}{\beta}} n l_y \\ &= Z_j(\theta_1, \theta_2, .., \theta_N, \lambda_1, \lambda_2, .., \lambda_N) \end{aligned} \tag{5.21}$$

Equation (5.20) now explains more clearly how pollution in each country depends indirectly on θ via the composite intermediate good. As explained before, a higher standard directly reduces the emission intensity per net unit of output (policy effect). It also reduces the unit input coefficient in the intermediate goods sector (direct technology effect). As for the impact of θ through the composite intermediate good, we can distinguish between two different effects. First, a higher standard reduces the domestic wage rate, reduces the country's share in world income, decreases production of the composite intermediate good and thereby reduces production and pollution in the intermediate goods sector (income effect). Second, a higher standard negatively affects the global productivity term G, although to a relatively minor extent in a world with many countries, and thereby again indirectly reduces pollution and production at home in the tradable goods sector (indirect technology effect or feedback).

Now that we have determined an expression for equilibrium pollution in the presence of IO-linkages (5.20), we are interested in the impact of a unilateral marginal change in environmental policy on equilibrium pollution, both at home and abroad. From the perspective of the mitigating country we can write domestic pollution and foreign pollution using (5.20) as:

$$\begin{aligned} z_A &= e(\theta_A)(1-\theta_A)(l_y)^\beta \left((\lambda_A)^{\frac{1}{\beta}} (\frac{1-\beta}{n})^{\frac{1-\beta}{\beta}} (G_A)^{\frac{1}{\beta}} l_y \right)^{1-\beta} \\ z_B &= e(\theta_B)(1-\theta_B)(l_y)^\beta \left((\lambda_B)^{\frac{1}{\beta}} (\frac{1-\beta}{n})^{\frac{1-\beta}{\beta}} (G_B)^{\frac{1}{\beta}} l_y \right)^{1-\beta} \end{aligned} \tag{5.22}$$

where $G_A = (\sum_i n((1-\theta_i)(\frac{\lambda_i}{\lambda_A})^{1-\beta})^{\frac{\varepsilon-1}{\varepsilon}})^{\frac{\varepsilon}{\varepsilon-1}}$, $G_B = (\sum_i n((1-\theta_i)(\frac{\lambda_i}{\lambda_B})^{1-\beta})^{\frac{\varepsilon-1}{\varepsilon}})^{\frac{\varepsilon}{\varepsilon-1}}$, $\lambda_A = \frac{I_A}{I^w}$ and $\lambda_B = \frac{I_B}{I^w}$. Let us define carbon leakage as the increase in emissions outside the country taking actions related to mitigation and define the following elasticities, $\varepsilon_{z,\theta} \equiv -\frac{dz_j}{d\theta_j}\frac{1-\theta_j}{z_j} = \frac{1}{\alpha}(1-\alpha(1-\beta)(a-b)) > 0$ and $\varepsilon^l_{z,\theta} \equiv -\frac{dz_i}{d\theta_j}\frac{1-\theta_j}{z_i} = -\frac{1}{N}\frac{1-\beta}{\beta}((1-\beta)(\frac{N}{N-1}a-b)-1) > 0$, where superscript l is a mnemonic for leakage. Now totally differentiate (5.22), subject to the definitions of G_A, G_B, λ_A and λ_B, with respect to θ_A, w_A and w_B, taking θ_B as given. Note that even though income shares will be independent of environmental policy in equilibrium due to our symmetric set-up ($\lambda_j = \frac{1}{N}$), ex-ante countries will take into account that they can affect relative income.[6] We can then state the following result:

Proposition 1 *An increase in the stringency of environmental policy:*
1) reduces pollution at home, that is, $\frac{dz_j}{d\theta_j} = -\varepsilon_{z,\theta}\frac{z}{1-\theta} < 0$.
2) causes negative (carbon) leakage, $\frac{dz_i}{d\theta_j} = -\varepsilon^l_{z,\theta}\frac{z}{1-\theta} < 0$ *if and only if* $\beta < 1$. *There is zero leakage* $(\frac{dz_i}{d\theta_j} = 0)$ *if there is no IO-structure* $(\beta = 1)$.

Interestingly, our finding of negative carbon leakage implies that there are actually positive spillover effects from domestic environmental policies. Most studies on environmental policies (or climate change policies) in open economies find opposite, negative results. This is an important issue since carbon leakage effects seriously reduce the effectiveness of unilateral mitigation efforts.

To understand the negative carbon leakage result we rely on the following interpretation. Like physical capital, intermediate goods are produced inputs. If countries reduce their supply of intermediate goods, imports of these goods by trading partners will fall. This reduction of imports represents a reduction of inputs and ceteris paribus production of output in the importing country must fall. As a result, pollution in the intermediate goods sector decreases (positive spillback effect).

We should stress that the negative carbon leakage effect is composed of several terms, including a positive substitution effect. As we show in the proof of proposition 1 in the appendix, this substitution effect induces more pollution abroad: via the terms-of-trade a decrease in the supply of intermediate goods to world markets is softened by an increase in supply abroad. The net effect, however, of more stringent environmental policy on foreign pollution is always negative.

One could easily introduce positive carbon leakage by modifying our basic model. For example, one could assume pollution in other sectors or assume a more complicated production function for final goods. With $\beta = 1$ we find that leakage is zero: in this case the total supply of intermediate goods depends on domestic policies only. Although this is probably an unrealistic aspect of the model, we feel that in its current shape the model clearly highlights the distinctive features of trade in intermediate goods and IO-linkages.

5.6 Environmental Policy in the Global Economy

5.6.1 A Variety of Externalities

Before we analyze the Nash equilibrium and the social optimum in more detail, it is helpful to distinguish between the various externalities that are present in the model. The list of externalities present in our framework reads:

[6] Only in a world with small open economies ($N \longrightarrow \infty$) will policymakers ignore this effect.

1. Firms do no take into account, unless corrective policy is in place, that the production of intermediate goods pollutes the (local) environment.
2. Firms (and governments) do not take into account that pollution spillovers from domestic production reduce welfare in other countries.
3. Governments take into account that a higher standard raises prices of inputs for domestic producers, but ignore the fact that price increases also fall on intermediate good producers and final good producers in other countries. Thus, they ignore the negative ramifications of higher prices on welfare in other countries.
4. A higher domestic standard reduces the total factor productivity G_j in the intermediate goods sector in all countries. Governments do not internalize the implications of this negative technology effect for welfare in other countries.

Given these different types of externalities, how then is the non-cooperative standard distorted? First of all, the implications of (1)-(2) are obvious. In the absence of global coordination on environmental policy, (1)-(2) tends to result in too much pollution from a social planner perspective. Second, ignoring price spillovers from domestic environmental policy can actually lead to too little pollution (3). Third and finally, (4) needs some additional explanation before proceeding to the analysis of the Nash equilibrium. The impact of environmental policy on the productivity term G in the tradable goods sector can be categorized as a negative technology spillover. Such negative technology spillovers will ceteris paribus decrease pollution in other countries, which in turn lowers spillovers to the domestic country. We refer to this additional effect as a *spillback* effect, similar to Ogawa and Wildasin (2009). Since countries will only internalize this spillback effect in as much it lowers their own pollution damages there is a tendency for too much pollution. Armed with this list, we are now ready to analyze the social optimum and the non-cooperative solution.

5.6.2 The Social Optimum

Before proceeding to the analysis of the social optimum we feel some remarks with respect to the utility function are in order. In this section and the next we focus on solutions with log-utility ($\sigma = 1$). Under different circumstances ($\sigma \neq 1$), there is a very strong tendency for the (non-cooperative) standard to increase when β decreases. To see why, we derive an implicit equation for the wage rate as a function of domestic environmental policy and foreign wages by rewriting the balanced trade condition (5.14) to:

$$(w_j)^{1+\beta(\varepsilon-1)} - n(1-\theta_j)^{\varepsilon-1} w_j = n(1-\theta_j)^{\varepsilon-1}(\sum_{i\neq j} w_i) \tag{5.23}$$

When countries are fully symmetric wages must equalize and (5.23) boils down to:

$$w = [(1-\theta)M^{\frac{1}{\varepsilon-1}}]^{\frac{1}{\beta}} \tag{5.24}$$

Keep in mind that w does not depend on σ. Now from (5.24) note first that $\lim_{\beta\to 0} w = \lim_{\beta\to 0}[(1-\theta)M^{\frac{1}{\varepsilon-1}}]^{\frac{1}{\beta}} = +\infty$ if $(1-\theta)M^{\frac{1}{\varepsilon-1}} > 1$. Provided this is the case one also finds, using (5.1), that

$\lim_{\beta\to 0}\frac{\partial u}{\partial c} = (w_j)^{-\sigma\tau} = 0$. In words, the marginal utility of consumption goes to zero. As we will see later on, unless we take a log-functional form for utility, the marginal cost of abatement will then go to zero as well when we strengthen the international input-output structure (lower β). Since we are not directly interested in the impact of income on the stringency of environmental regulation, we decide to adopt a log-utility function such that the marginal cost of meeting the domestic standard (MAC) will not depend on the wage rate.

Let us define global welfare by $u^w \equiv \sum_{j=1}^{N} u_j$. Then substitution of (5.1), $c_j = \frac{w_j}{p_{jC}} = w_j^\tau$ and (5.21) into u^w leads to

$$V^w = \sum_{i=1}^{N} \log w_i^\tau - \eta \sum_{i=1}^{N} Z_i(\theta_1, \theta_2, .., \theta_N, \lambda_1, \lambda_2, .., \lambda_N) \tag{5.25}$$

To ease comparison with the non-cooperative equilibrium, we decide to analyze the market implementation of the social optimum. To implement the social optimum each country selects a standard that equates the social marginal cost of abatement to the social marginal benefit of abatement[7]. Maximize (5.25) with respect to θ_j, and rearrange to obtain:

$$\underbrace{-\tau\left(\frac{1}{w_j}\frac{dw_j}{d\theta_j} + (N-1)\frac{1}{w_i}\frac{dw_i}{d\theta_j}\right)}_{\equiv MAC_j^S} + \underbrace{\eta n(1+\phi(N-1))\left(\frac{dz_j}{d\theta_j} + \phi(N-1)\frac{dz_i}{d\theta_j}\right)}_{\equiv -MB_j^S} = 0 \tag{5.26}$$

The first term on the left-hand side represents the social marginal cost of meeting the standard in util terms with a minus sign in front of it, that is, $MAC_j^S = -\tau\frac{1}{w_j}\frac{dw_j}{d\theta_j}$. A higher standard reduces wages at home and abroad, thereby reducing consumption and utility in all countries. The second term represents the marginal benefit of setting a standard or the marginal reduction in pollution damages from a higher standard. This marginal benefit of setting a higher standard results from reduced pollution at home via $\frac{dz_j}{d\theta_j}$ and an increase or decrease in foreign pollution via $\frac{dz_i}{d\theta_j}$. Before we present the solution to the optimal standard in the social optimum θ^S, we present the non-cooperative problem.

5.6.3 The Symmetric Nash Equilibrium

For the non-cooperative Nash equilibrium the problem of country $j = 1, .., N$ is to maximize $V_j = \log w_j^\tau - \eta Z_j(\theta_1, \theta_2, .., \theta_N, \lambda_1, \lambda_2, .., \lambda_N)$ with respect to θ_j taking the standards set by other countries as given. The solution θ_j^{NC} satisfies the following first-order condition

$$\underbrace{\tau\frac{1}{w_j}\frac{dw_j}{d\theta_j}}_{\equiv -MAC_j} \underbrace{-\eta n\left(\frac{dz_j}{d\theta_j} + \phi(N-1)\frac{dz_i}{d\theta_j}\right)}_{\equiv MB_j} = 0 \tag{5.27}$$

[7] Note that in the presence of international trade it is not sufficient to use private marginal cost of abatement (as it would be under autarky). Via trade a part of the costs from environmental policy automatically spill over to other countries in the form of higher prices.

for all $j = 1, .., N$. Like the social planner, each country will set the marginal cost of meeting the domestic standard (first term) equal to the marginal benefits of meeting the domestic standard (second and third term) when determining the optimal standard. Unlike the social planner, however, individual countries do not take into account how abatement increases prices in other countries as well. Another difference between the two solutions is that individual countries do not take into account that a lower emission intensity at home also benefits other countries by reducing pollution abroad (second term). Similarly, individual countries acknowledge that a loss of productivity in the intermediate goods sector lowers pollution abroad. The resulting spillback effect tends to raise the optimal standard, but individual countries ignore that these spillbacks improve welfare in other countries as well.

Now let us introduce the following notation:

Definition 1. *(i) In the symmetric non-cooperative equilibrium the marginal cost of meeting the domestic standard and the marginal benefits of meeting the domestic standard in each country can be defined as functions of N, that is, $MAC(N) = \Omega^C(N)\frac{1}{1-\theta}$ and $MB(N) = \Omega^B(N)(1-\theta)^{\Phi-1}$, where $\Omega^C(N) \equiv -\tau(a-b)$ and $\Omega^B(N) \equiv \eta n(\varepsilon_{z,\theta} + \phi(N-1)\varepsilon^l_{z,\theta})\bar{z}$ denote the MAC-coefficient and MB-coefficient respectively.*

(ii) *For the social optimum we define $MB^S(N) = \Omega^B_S(N)(1-\theta)^{\Phi-1}$ and $MAC^S(N) = \Omega^C_S(N)\frac{1}{1-\theta}$ where $\Omega^B_S = (1+\phi(N-1))\Omega^B$ and $\Omega^C_S = \Omega^C(1) = \tau b$.*

From (5.26) and (5.27), and making use of definition 1, we can now obtain closed-form solutions for θ^S and θ^{NC}. Equating the marginal cost of meeting the domestic standard to the marginal benefits of meeting the domestic standard yields:

$$\theta^{NC} = 1 - \left[\frac{\Omega^C(N)}{\Omega^B(N)}\right]^{\frac{1}{\Phi}} \quad , \quad \theta^S = 1 - \left[\frac{1}{1+\phi(N-1)}\frac{\Omega^C(1)}{\Omega^B(N)}\right]^{\frac{1}{\Phi}} \tag{5.28}$$

In turn, these solutions can be used to solve for Z^S and Z^{NC} by substituting from (5.28) into (5.21). The solutions under (5.28) satisfy the following properties[8]:

Proposition 2 *(i) Under transboundary pollution ($\phi > 0$) we find*
$\theta^S \gtrless \theta^{NC} \Leftrightarrow 1 \gtrless \frac{1+\phi(N-1)}{\phi(N-1)}\frac{N-1}{N}\frac{1}{1+\beta(\varepsilon-1)}$.
(ii) Under purely local pollution ($\phi = 0$) we have $\theta^S < \theta^{NC}$ for all $N > 1$.
(iii) There exists a unique $\bar{\phi} \equiv \frac{1}{N-1}\frac{a}{b-a} \in (0, 1]$ such that $\theta^S \gtrless \theta^{NC}$ for all $\phi \gtrless \bar{\phi}$. This threshold $\bar{\phi}$ is decreasing in β.

Proposition 3 *For $\phi < (>)\bar{\phi}$ we find that green welfare is higher (lower) in the non-cooperative equilibrium than in the social optimum.*

With spillovers from pollution ($\phi > 0$) both a race to the bottom type of result, which is typical for the tax competition literature, and a race to the top result, where standards are actually highest under decentralization, are feasible depending on various parameter values. A more detailed examination of

[8] Note that θ^S is still a function of N since the marginal benefits of abatement depend on N: we have assumed that $\phi \in [0, 1]$ such that ceteris paribus a more decentralized world leads to lower damages.

the condition under (i) might prove to be insightful here. A comparison of the two solutions under (5.28) tells us that the marginal costs of abatement are smaller under decentralization than in the social optimum. Based on this argument alone, the non-cooperative standard should be more stringent than the standard in the social optimum. However, the marginal benefits of abatement are $[1 + \phi(N-1)]$ times as large in the social optimum than in the non-cooperative equilibrium which tends to make the socially efficient standard higher than the non-cooperative standard. Thus, when the terms-of-trade externality overwhelms the free-riding externality we obtain a race to the top result ($\theta^S < \theta^{NC}$) otherwise we obtain a race to the bottom result ($\theta^S > \theta^{NC}$).

If pollution spillovers between countries are absent *($\phi = 0$)*, we find that non-cooperation results in a sub-optimal high equilibrium standard and sub-optimal low levels of pollution. How can we explain this result using our list of cross-country externalities? First, note that free-riding between nation states does not play any role when pollution is purely local. Second, in the absence of cooperation countries will impose production standards to raise the terms-of-trade, thereby increasing local environmental quality. Third, a strict standard reduces the aggregate technology in other countries. Since there are no spillbacks from pollution in this case, countries have no incentive to internalize this effect, which depresses TFP beyond the efficient level. Conclusively, in the absence of transboundary spillovers the non-cooperative solution is characterized by a higher level of environmental quality than the social optimum, due to "favorable" terms-of-trade effects and technology spillovers, and the absence of free-riding.

Part (iii) of proposition 2 shows that there exists a threshold value $0 < \bar{\phi} \leq 1$ for the spillover coefficient such that for all $\phi < \bar{\phi}$ we obtain a race to the top result and for all $\phi > \bar{\phi}$ we obtain a race to the bottom. Interestingly, part (iii) of proposition also states that the range (in terms of ϕ) for which race to the bottom results are obtained is increasing in β. In other words, the stronger the input-output structure of the world economy the larger the range of values of ϕ for which the non-cooperative standard leads to inefficiently high levels of environmental protection. Note that only in the unrealistic case of $\beta = 0$ we find that $\bar{\phi} = 1$; regulatory decoupling is sufficiently strong to overwhelm the free-riding effect for all degrees of transboundary spillovers. In addition, from the definition of $\bar{\phi}$ and the fact that the welfare function depends strictly on θ, we can also conclude (i) that welfare in the social optimum and the non-cooperative equilibrium coincide when $\phi = \bar{\phi}$ and (ii) that even with transboundary pollution it is possible that green welfare is highest in the non-cooperative equilibrium provided $\phi < \bar{\phi}$.

5.6.4 Decentralization and the Marginal Benefits of Environmental Policy

It is common knowledge among environmental economists that the marginal benefits of abatement are increasing with country size. There are at least two possible reasons for this. First, a more populous country simply captures a larger share of the benefits of its mitigation efforts. Since we have specified the welfare function on the basis of per capita utility, this mechanism is not at work in our model (although it could be added quite easily).

Related to the marginal benefit of abatement is the marginal benefit of meeting the domestic standard. Here country size plays a positive role as well: an increase in the stringency of environmental policy will lead to greater emission reductions in countries with larger endowments (labor, capital etc.) and higher output. Due to this share effect and endowment effect we find that the contribution to global public goods, at least in theory, tends to be correlated with country size (see Vickary (2009)). Indeed, in our model decentralization means a smaller labor force per country due to the fact that the population size of the world is fixed. Consequently, decentralization lowers the marginal benefits of meeting the domestic standard simply because smaller countries produce less (endowment effect). To see this clearly, assume $\beta = 1$ such that $\Omega^B = \eta\frac{1}{\alpha}\tau\frac{L^w}{N}$, which is strictly decreasing in N and where η is the constant marginal benefit of abatement.

In the remaining part of this section we are interested how decentralization affects the marginal benefits of meeting the domestic standard in the general case with input-output linkages ($\beta \neq 1$). The reasons for our interest are twofold. First, input-output linkages introduces new channels through which decentralization impacts the marginal benefits of environmental policy. Second, decentralization is of interest from an empirical perspective as well. In recent decades economic growth in numerous developing countries has lead to a decrease of the income share in world GDP of the traditional economic superpowers, Europe, the United States and Japan, giving rise to a new multipolar world economy. Essentially, decentralization captures the policy aspects related to this development since decentralization increases the strength by which the various externalities affect non-cooperative policies.

To commence our formal analysis, differentiation of $\Omega^B \equiv \eta(\varepsilon_{z,\theta} + (N-1)\varepsilon^l_{z,\theta})(n\bar{z})$ with respect to N shows us a a variety of channels:

$$\frac{\partial}{\partial N}(\Omega^B) = \frac{\Omega^B}{\varepsilon_{z,\theta} + \phi(N-1)\varepsilon^l_{z,\theta}}\frac{\partial(\varepsilon_{z,\theta} + \phi(N-1)\varepsilon^l_{z,\theta})}{\partial N} + \frac{\Omega^B}{n\bar{z}}\frac{\partial(n\bar{z})}{\partial N} < 0$$

The MB-coefficient consists of two terms. First, there is the elasticity of global pollution with respect to domestic environmental policy, $\varepsilon_{z,\theta} + \phi(N-1)\varepsilon^l_{z,\theta}$. Second, the marginal benefits of meeting the domestic standard are also increasing in $n\bar{z}$, which represents the upper bound on pollution (when there is no environmental standard). Note that the MB-coefficient also depends on the allocation of endowments across countries: asymmetric endowments of labor would lower the upper bound on pollution.[9] The first channel through which decentralization affects Ω^B is of some interest on its own:

Proposition 4 (*Desensitization of pollution with respect to local environmental policy). Under decentralization*

(i) *pollution in any given country becomes less responsive to local environmental policy* ($\frac{\partial(\varepsilon_{z,\theta}}{\partial N} < 0$ *and* $\frac{\partial \varepsilon^l_{z,\theta}}{\partial N} < 0$).

(ii) *total foreign pollution becomes more responsive to local environmental policy* ($\frac{\partial[\phi(N-1)\varepsilon^l_{z,\theta}]}{\partial N} > 0$).

(iii) *the responsiveness of global pollution is strictly negative* ($\frac{\partial(\varepsilon_{z,\theta}+\phi(N-1)\varepsilon^l_{z,\theta})}{\partial N} < 0$).

The impact of decentralization on the marginal benefits of meeting the domestic standard is strictly

[9] Since countries are completely specialized and the elasticity of substitution between different goods is equal, countries prefer to import equal amounts of each good. Similar to love-for-variety in consumption, an equal allocation is the optimal allocation.

negative, $\frac{\partial}{\partial N}(\Omega^B) < 0$. To explain the influence of IO-linkages in more detail, consider first the impact of decentralization on the upperbound of pollution $n\bar{z} = (\frac{1}{N})^{\frac{1-\beta}{\beta}} (\frac{N}{M}(1-\beta))^{\frac{(1-\beta)^2}{\beta}} \left(M^{\frac{\varepsilon}{\varepsilon-1}}\right)^{\frac{1-\beta}{\beta}} nl_y$. First, it includes the original endowment effect through nl_y. Second, there is a size effect that relates the size of the upstream industry (composite intermediate good) and the downstream industry (tradable intermediate good) in a particular country. A large country will have a larger upstream industry, a more than proportionally larger downstream industry and a more than proportionally larger level of pollution. This effect is reflected in the $(\frac{1}{N})^{\frac{1-\beta}{\beta}}$ term and explains that decentralization leads to a world with smaller countries and to smaller marginal benefits of pollution. Third and finally, if the number of intermediates decreases, then the total output per intermediate good increases given the total output of the intermediate goods sector. This positive effect of N on the marginal benefits of pollution is measured through the $(\frac{N}{M}(1-\beta))^{\frac{(1-\beta)^2}{\beta}}$ term. The overall effect of decentralization on the upper bound of pollution turns out to be negative. Next, decentralization also affects the responsiveness of pollution with respect to local environmental regulation. If countries become smaller the impact of any given country through environmental policy on pollution at home and in other countries diminishes ($\frac{\partial \varepsilon_{z,\theta}}{\partial N} < 0$, $\frac{\partial \varepsilon^l_{z,\theta}}{\partial N} < 0$ and $\frac{\partial(\varepsilon_{z,\theta}+\phi(N-1)\varepsilon^l_{z,\theta})}{\partial N} < 0$).

In our view, proposition 4 describes an important and a somewhat overlooked aspect of environmental policy in open economies. The fact that local pollution become less responsive to local policies in a decentralized world represents a separate pathway through which trade affects green welfare. To explain this effect in more detail, consider the following explanation. Refer to the sector producing the composite intermediate good as the upstream industry and the sector producing intermediate goods as the downstream industry. In any particular country, the downstream industry depends on inputs from the upstream industry and vice versa. In addition, the upstream industry depends on inputs of intermediate inputs from other countries as well. In this global web of downstream and upstream industries, the impact of environmental regulation is weakened when country size diminishes. In particular, the income effect and the technology/feedback effect of a marginal change in environmental policy, as described under (5.21), are diminished when the degree of decentralization increases.

Of course, in general one would expect the marginal benefits of abatement to be interdependent on the actions taken by other countries. A well-known example is the case in which the damage function is quadratic such that the marginal damage from pollution depends on global pollution. In this situation the marginal benefits of abatement are interdependent on mitigation efforts taken by other countries, even in autarky. An important question is whether desensitization of local emissions with respect to local environmental policy is present in other trade models and, if so, whether the opposite effect of increased responsiveness, is also feasible. This presents an interesting question for future research.

5.6.5 Global Welfare, Green Welfare and other properties of the Nash equilibrium

Next, let us discuss a few interesting properties of the non-cooperative standard under transboundary pollution. In what follows we will be mainly concerned with the impact of decentralization (N) and the impact of IO-linkages (β).

First of all, analytically we find that the non-cooperative solution is ambiguous with respect to N ($\frac{\partial\theta^{NC}}{\partial N} \gtrless 0$) because of three opposing effects. On the one hand, decentralization ($N \uparrow$) exacerbates the spillback motive and free-riding motive which tends to decrease the optimal standard ($\theta^{NC} \downarrow$). On the other hand, regulatory decoupling increases under decentralization ($N \uparrow$) and via a lower marginal cost of abatement increases the optimal standard ($\theta^{NC} \uparrow$).

Using (5.28) we also find that stronger input-output linkages potentially lead to a higher standard when countries do not cooperate ($\frac{\partial\theta^{NC}}{\partial\beta} \gtrless 0$). How can we explain this ambiguity? We find that the effects of a marginal change in β on both the marginal cost of meeting the domestic standard and the marginal benefits from meeting the domestic standard are ambiguous. Even more interesting, the free-riding effect is possibly diminished in case technologies are characterized by a stronger input-output structure ($\frac{\partial}{\partial\beta}(\frac{\partial\theta^{NC}}{\partial N}) \lesseqgtr 0$).

To explore the ambiguity in some of our results in more detail, we conduct some numerical experiments. Figure 1 depicts the level of the (non)-cooperative standard as a function of the degree of centralization (N) and the strength of the input-output linkages (β). We take the following parameters: $\alpha = 0.3$, $\tau = 0.5$, $\varepsilon = 2$, $M = 1$, $L^w = 10$ and $\eta = 10$. The following observations stand out:

- Ceteris paribus a higher level of decentralization lowers the non-cooperative standard.
- Stronger input-output linkages reduce the non-cooperative standard.
- The negative impact of decentralization on the non-cooperative standard does not seem to be affected by the strength of the IO-structure.

The first observation tells us that, even though we have not been able to derive an analytical proof, the non-cooperative standard decreases monotonically under decentralization. We also find that a stronger input-output structure decreases the optimal standard. So far we have not been able to find parameter values that show otherwise. The third observation explains that even though in theory a stronger IO-structure could mitigate the negative effects of decentralization, our numerical experiments indicate that the overall effect is likely to be small ($\frac{\partial}{\partial\beta}(\frac{\partial\theta^{NC}}{\partial N}) \approx 0$).

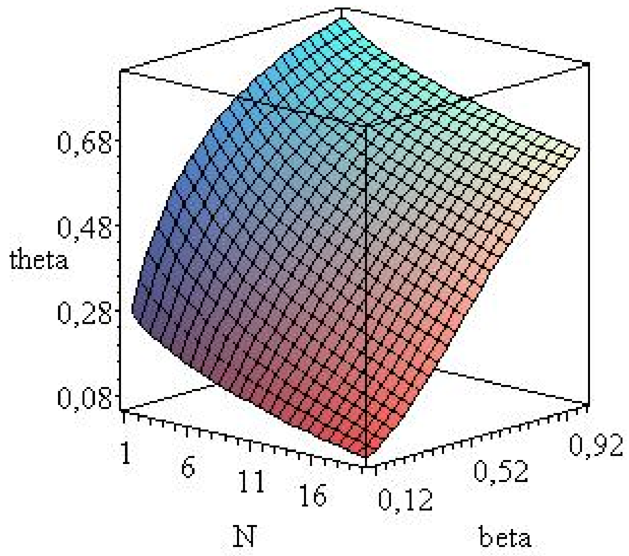

Figure 1a: The impact of decentralization & IO-linkages on the optimal standard.

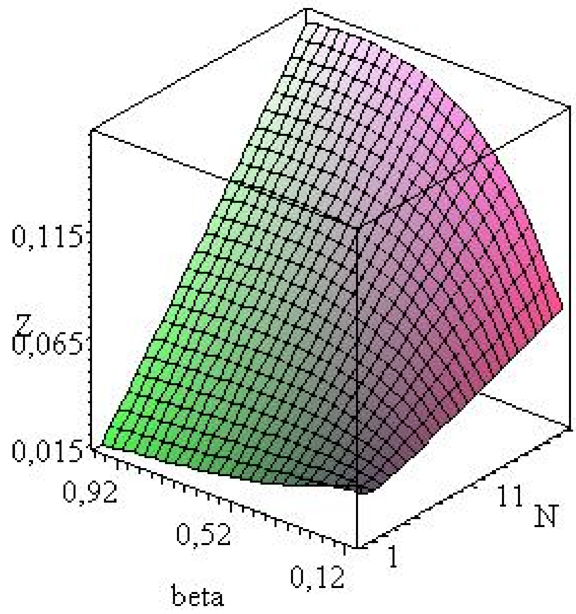

Figure 1b: Can IO-linkages reduce global pollution?

Like the equilibrium properties of the non-cooperative standard it is not trivial to unambiguously sign the derivatives of equilibrium pollution with respect to N and β. A change in the input-output structure of the world economy, as captured by the parameter β, affects world pollution through three different channels. Summing up, the various effects can be categorized as allocation effects, indirect effects through the non-cooperative standard and effects on the elasticity of world pollution with respect to environmental policy Φ (see the appendix). All in all, the total effect on world pollution of a change in β is ambiguous.

We depict the effects of decentralization and the strength of input-output linkages on global pollution in figure 1b. Again, the results that follow from this numerical exercise are quite clear. First, the level of global pollution is increasing in the degree of decentralization. As was evident from the explanation following proposition 2, this is caused by the overwhelming impact of free-riding on the willingness to reduce emissions. Second, and closely related to the previous observation, decentralization increases global pollution but the extent to which is strongly reduced if input-output linkages are stronger (low β). Thus, even though the non-cooperative standard is lower when IO-linkages are stronger (see figure 1a), numerical experiments indicate that for most parameter values the effects on global pollution are actually positive: strong linkages reduce pollution, especially when decentralization is high.

5.7 Other Interdependencies: The Role of International Factor Ownership

In this section we add international factor ownership to our framework and investigate its consequences for global environmental quality. To begin with, why should we be interested in another economic interdependency? There are at least two reasons. First of all, economists have known for some time that intra-industry trade is often accompanied by a strengthening of economic relations in other domains as well, which include (i) international factor ownership, (ii) international equity ownership and (iii) multinational production. Second, international factor ownership represents an additional source of regulatory decoupling: if a certain fraction of domestically employed factors of production is owned by foreigners, then foreigners will directly bear the costs of environmental policy imposed by domestic regulators in the form of lower factor returns. Under these conditions it seems both relevant and interesting to find out whether this issue can add to our understanding of regulatory decoupling. In what follows we will explore the consequences of international factor ownership and leave the other interdependencies for future research. We take the degree of international factor ownership as given: we focus on the implications of this interdependency for environmental policy, not its causes. As far as we know, Lee (2005) is the only one to consider the relationship between international factor ownership and non-cooperative environmental policies, but he does not consider transboundary pollution. Lee (2005) also abstracts from considerations with respect to expenditure shifting, a concept that we will explain in the remaining part of this section.

5.7.1 International Factor Ownership, Expenditure Shifting and the Balance of Trade

To operationalize international factor ownership in our framework we introduce two key assumptions. First, to retain symmetry we assume that each country owns a share $1-\delta$ of all "labor" employed at home. Each country also holds a claim on production factors abroad with a cumulative share of δ, that is, $\sum_{i\neq j}\delta_{ji}^{L}=\delta$ where δ_{ji}^{L} is the claim on labor employed in country i by country j. This cumulative share is equally divided across the remaining countries such that $\delta_{ji}^{L}=\frac{1}{N-1}\delta$ for all i,j. Second, we assume that international factor ownership is accompanied by expenditure shifting: foreign owned factors of production spend a share h of their income on consumption in the country of the owner (their home country) and the remaining share of $1-h$ in the country of employment. Lee (2005) only considers the case of $h=1$.

Then, under international factor ownership, gross national income I_j of country j is now defined as the sum of income earned at home and abroad, $I_j=(1-\delta)w_jL+\frac{1}{N-1}\delta\sum_{i\neq j}w_iL$. Gross domestic income I_j^d equals total payments to domestically employed factors of production, that is, $I_j^d=w_jL$. Total expenditures on consumption in country j equal $I_j^c=(1-\delta)w_jL+h\frac{1}{N-1}\delta\sum_{i\neq j}w_iL+(1-h)\delta w_jL$. Observe that $I_j=I_j^c$ when $h=1$ and $I_j=I_j^d=I_j^c$ in case $h=0$. In the appendix we show that the balanced trade condition under international factor ownership ($\delta>0$) is defined as:

$$[I_j^d-(1-\tau)I_j^c]=\tau n(p_j)^{1-\varepsilon}I^w \tag{5.29}$$

where on the left-hand side we get $[I_j^d - (1-\tau)I_j^c] = \tau I_j$ as a special case whenever there is no expenditure shifting ($h = 0$).

In the presence of symmetric countries gross domestic income and gross national income will coincide in equilibrium. Nevertheless, ex ante the difference between these income measures affects the incentives for policymakers who are occupied with the determination of environmental policy. International factor ownership alters the marginal cost of abatement, as determined by domestic policy makers, on two accounts:

- Policy makers will now internalize changes to the foreign wage rate in as much it affects domestic welfare; a natural consequence in a world where a part of national income is earned abroad. As a result, policy makers partially internalize terms-of-trade externalities. In this sense, international factor ownership serves to undo the terms-of-trade dilemma that is also present in this model (see also Blanchard (2010)).
- Second, under international factor ownership the effects of abatement on TFP will in part be borne by foreign owners of domestic factors of production.

Before we turn to the topic of optimal policies again, we have to determine $\frac{dw_j}{d\theta j}$ and $\frac{dw_i}{d\theta j}$ given the novel assumptions of international ownership. In the appendix we show that these derivatives can again be formulated by referring only to TFP and terms-of-trade effects:

$$\frac{dw_j}{d\theta_j} = (a_O - b)p^0 < 0 \quad , \quad \frac{dw_i}{d\theta_j} = -\frac{1}{N-1}a_O p^0 < 0 \tag{5.30}$$

where $a_O(\delta, h) \equiv \frac{1}{\beta}\frac{N-1}{N}\frac{\Delta}{\Delta+\tau(N-1)\beta(\varepsilon-1)} > 0$ denotes the terms-of-trade coefficient with international factor ownership (O), $\frac{\partial a_O}{\partial \delta} = \frac{N(1-\tau)h}{\Delta}\frac{\tau(N-1)\beta(\varepsilon-1)}{\Delta+\tau(N-1)\beta(\varepsilon-1)}a_O > 0$, $\frac{\partial a_O}{\partial h} = \frac{N(1-\tau)\delta}{\Delta}\frac{\tau(N-1)\beta(\varepsilon-1)}{\Delta+\tau(N-1)\beta(\varepsilon-1)}a_O > 0$ and $\Delta \equiv N(1-\tau)h\delta + \tau(N-1)$.

As it turns out, expenditure shifting ($h > 0$) is a necessary condition in order for international factor ownership to affect the comparative statics in (5.30). In case $h = 0$ the results under (5.30) coincide with those in the previous section. For the more general case of $h > 0$ several noteworthy results are obtained. First, the terms-of-trade coefficient a_O is strictly increasing in δ, provided $h > 0$. Second, using (5.30) this means that $\frac{d}{d\delta}(\frac{dw_j}{d\theta_j}) = a'_O(\delta)p^0 > 0$, excluding indirect effects via p^0. In words, the larger the share of income earned abroad the smaller the impact of more stringent environmental policy on the domestic wage rate. Why is this the case? Why is a_O strictly increasing in δ? The answer lies in the new formulation of the current account (5.29). When international factor ownership leads to expenditure shifting, imports (the left-hand side of (5.29)) depend on both domestic income as well as foreign income receipts. To unravel the exact working of this mechanism note that a change in δ has two effects on the current account. On the one hand a change in δ decreases the claim on domestic factors of production, thereby decreasing national income and imports. On the other hand, there is also an opposite effect since it increases the claim on foreign factors of production thereby increasing national income and increasing demand for exports. The net effect is that a higher claim on foreign factors of production mitigates the negative effect from a higher standard on the domestic wage rate.

5.7.2 International Factor Ownership, Rent Extraction and Environmental Regulation

The fundamental property of international factor ownership, which might either reflect various forms of international investment or migration of labor, is that it generates differences in levels between a country's gross domestic product and gross national product. Interestingly, international investors will bear a part of the costs from environmental regulation since they own a fraction of domestically employed factors of production. In the absence of tax policy instruments, a welfare maximizing government might use environmental policy to extract rents from foreigners. To see this, note that the terms-of-trade coefficient can be rewritten as

$$a_O = \underbrace{\frac{1}{\beta}\frac{N-1}{N}\frac{1}{\frac{1-\tau}{\tau}\delta h + 1 + \beta(\varepsilon - 1)}}_{\text{terms-of-trade}} + \underbrace{\frac{1}{\beta}\frac{N-1}{N}\frac{\frac{1-\tau}{\tau}\delta h}{\frac{1-\tau}{\tau}\delta h + 1 + \beta(\varepsilon - 1)}}_{\text{rent extraction}}$$

where the first term refers to the terms-of-trade effect and the second term is a "rent-extraction" effect. A few additional observations can be made. First, the intermediate goods multiplier affects both the terms-of-trade effect as well as the rent-extraction motive. Second, while the terms-of-trade effect is strictly decreasing in the coefficient δ the rent extraction motive is increasing in this share. Third, the overall effect of the degree of international factor ownership on a_O is strictly positive. Thus, a high degree of international economic integration, as measured by δ, will ceteris paribus increase the stringency of environmental policy since a higher a_O coefficient will decrease the opportunity cost of environmental regulation.

5.7.3 The Symmetric Nash Equilibrium with International Factor Ownership

Now let us assume that each country again maximizes country welfare with respect to θ_j taking the standards set by other countries as given. An additional complication here is whether a national government should now be concerned with *domestic* consumption per capita or *national* consumption per capita. National consumption per capita reflects total expenditures on consumption per capita, at home and abroad, from total factor income to factor owners in country j. This is relevant because with international factor ownership and expenditure shifting a part of national income will be consumed in other countries. For example, migrants spend a part of income in their country of origin in the form of remittances that are send back to families etc. We will assume that the national government is concerned with national consumption per capita. In words, consumption per capita of total factors owned by country j is now given by $c_j = \frac{C_j^j}{L} + \frac{\sum_{i\neq j} C_j^i}{L} = \frac{(1-\delta)w_j + h\frac{1}{N-1}\delta\sum_{i\neq j} w_i}{w_j^{1-\tau}} + \sum_{i\neq j}\frac{(1-h)\frac{1}{N-1}\delta w_i}{w_i^{1-\tau}}$, where C_j^j and C_j^i are defined as respectively consumption in country j by factors owned and employed in j and consumption in country i by factors of production employed in i but owned by j.

The first-order condition of a representative country now reads:

$$\underbrace{\frac{1}{c_j}\frac{dc_j}{d\theta_j}}_{\equiv -MAC_j} = \underbrace{\eta n(\frac{dz_j}{d\theta_j} + \phi(N-1)\frac{dz_i}{d\theta_j})}_{\equiv -MB_j}$$

As we show in the appendix, the marginal cost of meeting the standard, $\frac{1}{c_j}\frac{dc_j}{d\theta_j}$, now consists of four different terms. The first term corresponds to nominal income earned and consumed in the home country. The second term represents income earned abroad but consumed in the home country. This means that policy makers will also take the effect of domestic policies on foreign wages into account. The third term measures the marginal change in the domestic consumer price as a result of a marginal change in the domestic standard. Together, these first three terms relate the real income that is consumed at home. The fourth and last term measures the impact on real income earned and consumed abroad. Together, these four terms measure the marginal change in utility from national consumption per capita from a marginal change in the domestic standard. We observe that the marginal benefits of meeting the domestic standard are not directly affected by the presence of international factor ownership.

Since international factor ownership and expenditure shifting affect the terms-of-trade coefficient a_O, the elasticities of pollution with respect to changes in environmental policy are affected as well. We define $\varepsilon^{O}_{z,\theta} \equiv \frac{1}{\alpha}(1-\alpha(1-\beta)(a_O-b)) > 0$ and $\varepsilon^{l,O}_{z,\theta} \equiv -\frac{1}{N}\frac{1-\beta}{\beta}((1-\beta)(\frac{N}{N-1}a_O-b)-1) > 0$ analogously to the definitions under (5.22). Using the derivatives in (5.30) we can write:

Definition 2. *In the symmetric non-cooperative equilibrium with international factor ownership the marginal cost of meeting the domestic standard and the marginal benefits of meeting the domestic standard equal respectively* $MAC = \Omega^C_O\frac{1}{1-\theta}$ *and* $MB = \Omega^B_O(1-\theta)^{\Phi-1}$*, where* $\Omega^C_O \equiv -(\tau-\delta)(a_O-b) + ((1-\tau)h+\tau)\delta\frac{1}{N-1}a_O$ *and* $\Omega^B_O \equiv \eta n(\varepsilon^{O}_{z,\theta} + \phi(N-1)\varepsilon^{l,O}_{z,\theta})\bar{z}$ *respectively denote the MAC-coefficient and MB-coefficient under international factor ownership.*

Using definition 2 we can show that the effect of δ on Ω is ambiguous, that is, $\frac{\partial\Omega^C_O}{\partial\delta} = (a_O-b) - (\tau-\delta)a'_O(\delta) + ((1-\tau)h+\tau)\frac{1}{N-1}a_O + ((1-\tau)h+\tau)\delta\frac{1}{N-1}a'_O(\delta) \gtreqless 0$. Thus, the effect of international factor ownership on the marginal cost of meeting the domestic standard is unclear. As expected, foreign ownership does not directly affect the marginal benefits from abatement. In conclusion, we find that international factor ownership has an ambiguous effect on the non-cooperative standard. Consequently, international factor ownership also has an ambiguous effect on global environmental quality. Next, consider the following proposition.

Proposition 5 *There exists a unique* $\bar{\phi}_O \equiv \frac{1}{N-1}\frac{\tau b-\Omega^C_O}{\Omega^C_O} \in [0,1]$ *such that* $\theta^S_O \gtreqless \theta^{NC}_O$ *for all* $\phi \gtreqless \bar{\phi}_O$*. This threshold* $\bar{\phi}_O$ *is decreasing in* β*, ambiguous in* δ *and ambiguous in* h*.*

The closed-form solution for the non-cooperative standard under international factor ownership reads $\theta^{NC}_O = 1 - \left(\frac{((1-\tau)h+\tau)\delta\frac{1}{N-1}a_O-(\tau-\delta)(a_O-b)}{\eta n(\varepsilon^{O}_{z,\theta}+\phi(N-1)\varepsilon^{l,O}_{z,\theta})\bar{z}}\right)^{\frac{1}{\Phi}}$. The coefficient Ω^C_O tells us that two terms are crucial to the marginal cost of meeting the domestic standard and, subsequently, the optimal standard. The first term, $((1-\tau)h+\tau)\delta\frac{1}{N-1}a_O$, represents the product of the claim on foreign endowments and the marginal cost of meeting the domestic standard in terms of a lower real wage abroad. A high value indicates that national income is adversely affected by the negative repercussions of domestic environmental policy abroad, which tends to lower the optimal standard. The second term of Ω^C_O summarize the negative effects of environmental policy on the real domestic wage rate. To see why, note that $\tau - \delta$ can be written as $(1-\delta)-(1-\tau)$, the share of income earned locally minus the expenditure share of domestic final good producers on labor. If $\tau - \delta < 0$ then the share of income earned abroad is relatively high and $-(\tau-\delta)(a_O - b) < 0$. If this is the case, the effect of a standard on real income is relatively weak or even positive and and as a result the optimal standard should increase.

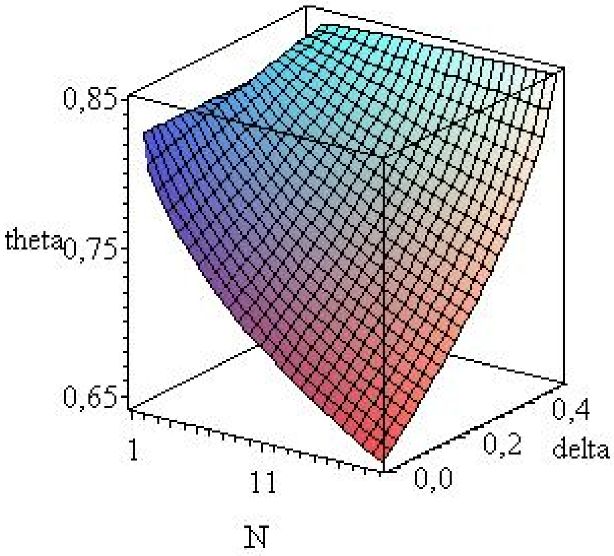

Figure 2a: Ownership & the non-cooperative standard.

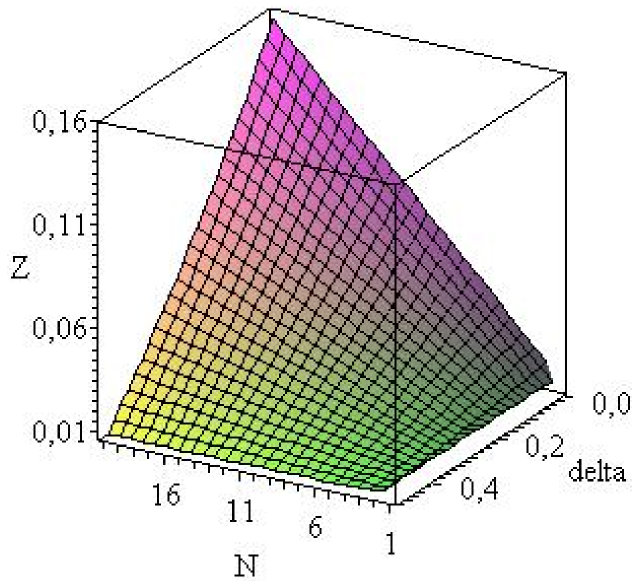

Figure 2b: Can international factor ownership reduce global pollution?

To conclude our discussion of international factor ownership, we again rely on numerical analysis to further clarify some of the results. We set all parameters to the same values as those that were chosen in the previous section. Our focus shifts to the impact of decentralization (N) and the degree of international factor ownership (δ). We assume $\beta = 1$ in order to clearly separate the effects from international ownership from those resulting from IO-linkages. The picture that emerges from our numerical experiments is clear. We find that decentralization lowers the optimal standard and raises global pollution. Nevertheless, the presence of international factor ownership unambiguously raises the stringency of environmental policy and lowers global pollution. Similar to the effect of IO-linkages, an increase in international factor ownership diminishes the negative impact of decentralization. Thus, both the presence of IO-linkages and international factor ownership seem to provide policy makers with incentives that actually mitigate the negative effects of decentralization on global pollution.

5.8 Standards under Endogenous Openness

In the previous sections production of the consumption good was characterized by a Cobb-Douglas functional form, where τ measured the income expenditure share on intermediates. As Acemoglu and Ventura (2002) note, τ can be interpreted as a measure of openness. In our set-up an alternative, but equally valid interpretation holds that τ measures the (global) expenditure share on dirty goods. A consequence of this assumption is that trade intensity is unaffected by changes in import prices and export prices and that the expenditure share on dirty goods is constant. To investigate the consequences of this rather restrictive assumption, we extend the model by incorporating a CES-production function in the final goods sector such that the degree of openness becomes endogenous.

Next, we adopt the following functional form for the final goods sector, $C_j = [(1-\tau)(L_{jC})^{\frac{\xi-1}{\xi}} + \tau(X_{jC})^{\frac{\xi-1}{\xi}}]^{\frac{\xi}{\xi-1}}$, which corresponds to the following price:

$$p_{jC} = [(1-\tau)^{\xi}(w_j)^{1-\xi} + \tau^{\xi})]^{\frac{1}{1-\xi}} \tag{5.31}$$

where (5.31) boils down to equation (5.8) in the limiting case of $\xi = 1$. In the appendix we then explain how the balanced trade condition can be reformulated as

$$\left[1-(1-\tau)^{\xi}(\frac{w_j}{p_{jC}})^{1-\xi}\right] I_j = \beta n(p_j)^{1-\varepsilon}\left[\tau^{\xi}\left(\sum_{i=1}^{i=N}(p_{iC})^{\xi-1}I_i\right) + \frac{1-\beta}{\beta}\tau I^w\right] \tag{5.32}$$

From (5.32) we deduce that trade intensity in the CES case depends on the domestic wage, $\upsilon(w) = 2\frac{N-1}{N}\frac{\tau^{\xi}(w_i^{1-\tau})^{\xi-1}I_j + \frac{1-\beta}{\beta}\tau I_j}{I_j} = 2\frac{N-1}{N}(\tau^{\xi}w_i^{(1-\tau)(\xi-1)} + \frac{1-\beta}{\beta}\tau)$ where $\upsilon'(w) \gtreqless 0$ for $\xi \gtreqless 1$. In words, if domestic labor and the composite intermediate good are substitutes (complements) in the production of the final good, then an increase in the domestic wage rate implies an increase (decrease) in trade intensity. The effect of an increase in the domestic standard on υ, $\frac{d\upsilon_j}{d\theta_j} = \upsilon'(w_j)\frac{dw_j}{d\theta_j}$, depends on the sign of $\frac{dw_j}{d\theta_j}$ and $\upsilon'(w_j)$. Assuming $\frac{dw_j}{d\theta_j} < 0$ we find

$$\frac{d\upsilon_j}{d\theta_j} = \upsilon'(w_j)\frac{dw_j}{d\theta_j} \gtreqless 0 \text{ for } \xi \lesseqgtr 1$$

To find out whether $\frac{dw_j}{d\theta_j}$ is indeed negative under endogenous openness, we first define $s_L^T \equiv \frac{w_j L_{jy}}{I_j} = \left[1-(1-\tau)^{\xi}(\frac{w_j}{p_{jC}})^{1-\xi}\right]$ as the share of labor income in the tradable sector over national income. Total differentiation of the price index equation and (5.32) then leads to the following derivatives:

$$\begin{aligned}\frac{dw_j}{d\theta_j} &= (\underbrace{-\frac{1}{\beta}}_{\text{TFP effect}} + \underbrace{\frac{1}{\beta}\frac{N-1}{N}\frac{1}{1+\beta(\varepsilon-1)+\epsilon_{Ly}^w}}_{\text{terms-of-trade effect}}\underbrace{-\frac{1}{\beta}\frac{1}{N}\frac{(\epsilon_{\upsilon}^w - N\epsilon_{Ly}^w)}{1+\beta(\varepsilon-1)+\epsilon_{Ly}^w}}_{\text{trade volume effect}})p^0 \\ &= (a_V(\theta) - b + r_j(\theta))p^0\end{aligned} \tag{5.33}$$

$$\frac{dw_i}{d\theta_j} = -\frac{1}{N-1}(a_V(\theta) - r_i(\theta))p^0 \tag{5.34}$$

where $\epsilon^w_{Ly} \equiv \frac{ds^T_L}{dw}\frac{w}{s^T_L} = \tau(\xi-1)(1-\tau)^{\xi}\left(\frac{(w)^{\tau(1-\xi)}}{1-(1-\tau)^{\xi}(w^{\tau})^{1-\xi}}\right)$ and $\epsilon^w_{\upsilon} \equiv \frac{d\upsilon}{dw}\frac{w}{\upsilon} = \frac{\tau^{\xi}(1-\tau)(\xi-1)w^{(1-\tau)(\xi-1)}}{\tau^{\xi}w^{(1-\tau)(\xi-1)}+\frac{1-\beta}{\beta}\tau}$ are respectively the wage elasticity of the income share of labor employed in the tradable sector and the wage elasticity of the intensity of trade. For both elasticities there is a one-on-one relationship with their sign and ξ, that is, $\epsilon^w_{Ly} \gtreqless 0$ and $\epsilon^w_{\upsilon} \gtreqless$ for $\xi \gtreqless 1$. Furthermore, $r_j(\theta) \equiv -\frac{1}{\beta}\frac{1}{N}\frac{(\epsilon^w_{\upsilon}-N\epsilon^w_{Ly})}{1+\beta(\varepsilon-1)+\epsilon^w_{Ly}}$ represents the marginal change in the volume of trade in country j and $r_i(\theta) \equiv r_j(\theta) - S(\theta)$ represents the marginal change in the volume of trade in country i, where $S(\theta) \equiv \frac{1}{\beta}\frac{1+\epsilon^w_{Ly}}{1+\epsilon^w_{\upsilon}} - \frac{1}{\beta}\frac{\varepsilon+\epsilon^w_{Ly}}{1+\beta(\varepsilon-1)+\epsilon^w_{Ly}} > 0$ represents a new production inefficiency effect.

An obvious difference between the CES-case and the Cobb-Douglas case is the appearance of trade-volume effects. With expenditure shares on inputs in the final goods sector no longer constant, the terms-of-trade effects that result from non-cooperative environmental policies also cause distortions of production choices. Although the sum of the terms-of-trade effects across all nations is zero, this is not the case with the trade-volume effects.[10] In this sense, $S(\theta)$ represents the global production inefficiency that is caused as a result of a marginal change in environmental policy in the mitigating country. This leads us to the following result:

Result 5 *If the intensity of trade is endogenous then*

(i) *the costs of environmental policy in the mitigating country are affected by an ambiguous change in the volume of trade (trade volume effect). If the volume of trade decreases (increases), $r_j(\theta) < (>)0$, then the costs are increased (diminished), provided that $\xi > 1$. If $\xi < 1$ then all results are reversed.*

(ii) Prices and wages in other countries are again affected by negative terms-of-trade spillovers, but also by an ambiguous trade volume effect as well as a negative production efficiency effect.

Equation (5.33) tells us that the new trade volume effect for the mitigating country is composed of two terms. These terms exert opposite effects on the domestic wage rate. Suppose that $\xi > 1$. First, there is a negative demand effect, $-\frac{1}{\beta}\frac{1}{N}\frac{\epsilon^w_{\upsilon}}{1+\beta(\varepsilon-1)+\epsilon^w_{Ly}} < 0$ for $\xi > 1$. This effect works as follows. A higher standard has a direct upward effect on prices of exports. These price increases lower global demand for domestic intermediates and it is this decrease in demand that decreases the intensity of trade. Via (5.32) a lower global demand for domestic intermediates will result in a lower wage. Second, there is a positive supply effect, $\frac{1}{\beta}\frac{1}{N}\frac{N\epsilon^w_{Ly}}{1+\beta(\varepsilon-1)+\epsilon^w_{Ly}} > 0$ for $\xi > 1$. A higher standard decreases the wage rate, raises the share of labor in the final goods sector, therefore suppresses the supply of domestic intermediates and via the balanced trade condition this tends to raise the domestic wage. With $\xi < 1$, when labor and intermediates are complements, these mechanisms are reversed and a higher standard leads to a positive demand effect and a negative supply effect.

As it turns out, it becomes quite complex to come-up with an analytical solution for the non-cooperative standard. Therefore we will now shortly sketch the solution for the special case of $\beta = 1$ (no IO structure). Assume $\phi = 1$. Then one can show that $MAC = \Omega^C_V \frac{1}{1-\theta}$ and $MB = \Omega^B_V(1-\theta)^{\frac{1-\alpha}{\alpha}}$ where $\Omega^C_V \equiv -\tau(p_C)^{\xi-1}(a_V(\theta) - b + r_j(\theta))$, $\Omega^B_V \equiv -\eta(-\frac{1}{\alpha} + \varepsilon^T(b+S))s^T_L$ and $\varepsilon^T \equiv \frac{ds^T_L}{d(w/p_C)}\frac{w/p_C}{s^T_L}$. The introduction of an endogenous expenditure share on tradables/dirty goods modifies the analysis in two ways. On the one hand, it increases the marginal benefits of a higher standard (via $\varepsilon^T(b+S)$) . This

[10]Formally, one finds $\frac{dp_j}{d\theta_j} + (N-1)\frac{dp_i}{d\theta_j} = S(\theta)\frac{p}{1-\theta}$.

is because a higher standard will lead to higher prices and as long as $\xi > 1$ this will lead to a contraction of the dirty goods sector. On the other hand, and depending on various parameters, an increase (decrease) in the volume of trade raises (lowers) the marginal cost of meeting the domestic standard ($r_j(\theta) > (<) 0$). Thus, we conclude that the net effect of an endogenous expenditure share on dirty goods is ambiguous.

5.9 Conclusion

In this chapter we have analyzed the impact of three different, but related aspects of globalization on environmental quality. Whereas previous work was primarily concerned with the effects of (i) trade openness, we also considered the impact of (ii) trade in intermediate goods coupled with vertical specialization and (iii) international factor ownership, relatively recent phenomena in the ongoing process of globalization. The purpose of this analysis was to investigate the possibility of a race to the top.

In countries with a high trade intensity regulators are faced with relatively low costs of abatement since part of these costs fall on foreign consumers via higher prices. Surprisingly, it was then found that domestic policy makers might impose excessively stringent environmental policies. We extended this idea by considering input-output linkages and international factor ownership and were also able to analyze the implications for global welfare. We showed that the stringency of environmental policy is simultaneously influenced by terms-of-trade effects, TFP effects, free-riding motives and spillback effects. The strength of these various effects depends on the degree of decentralization, which in turn is directly related to trade intensity.

A surprising result is that in a world with trade in intermediate goods, mitigating countries do not have to worry about carbon leakage. More stringent regulation lowers the supply of intermediate goods to world markets. Since intermediate inputs, like physical capital, are produced inputs a decrease in their supply will lower pollution in the importing countries. We also found that, depending on the degree of spillovers, global environmental quality can be either higher in the social optimum or the non-cooperative equilibrium. A race to the top, however, is more likely for local pollution than global pollution, unless one is willing to assume an unrealistically strong IO-structure. Thus, in the absence of global cooperation underprovision of global environmental quality remains an important issue.

We find that international factor ownership adds to our understanding of regulatory decoupling. Cross-ownership of factors of production implies that a part of the costs from environmental policy are directly borne by local factors of production owned by foreigners. This implies once again that policymakers are likely to implement excessively stringent environmental policy if one follows this argument alone. Of course, free-riding continues to form a strong force that leads to underprovision of the global public good. Finally, using numerical analysis we find that global pollution diminishes with stronger IO-linkages as well as with stronger degrees of international factor ownership.

The model used in this chapter was deliberately simple, thereby allowing for a full range of analytically tractable results. Future work might focus on the implications of models where specialization patterns are endogenous, as well as examining the case with an endogenous number of global varieties. Another point of interest is to repeat the analysis with asymmetric countries. Probably more interesting is a more detailed assessment of climate change policy instruments in the presence of both international (and national) input-output structures (see Leontieff (1970) and Levinson (2009)). This seems especially interesting in the context of certain sectors, such as energy and transportation. These sectors seem of vital importance to the world economy as measured by the degree to which they are linked to other sectors in the global economy.

5.9.1 Proofs of Results and Propositions

Result 1 *More stringent environmental policy reduces the domestic wage rate,*

$$\frac{dw_j}{d\theta_j} = (\underbrace{\frac{1}{\beta}\frac{N-1}{N}\frac{1}{1+\beta(\varepsilon-1)}}_{ToT}\underbrace{-\frac{1}{\beta}}_{TFP})p^0 = (a-b)p^0 < 0,$$

via a negative TFP effect ($-bp^0 < 0$) *and a positive terms-of-trade effect* ($ap^0 > 0$)*, where* $a \equiv \frac{1}{\beta}\frac{N-1}{N}\frac{1}{1+\beta(\varepsilon-1)}$ *and* $b \equiv \frac{1}{\beta}$ *denote respectively the terms-of-trade coefficient and the TFP coefficient. Foreign wages are affected as well via terms-of-trade spillovers,* $\frac{dw_j}{d\theta_j} = -\frac{1}{N-1}ap^0 < 0$*. Prices of intermediate goods increase at home and decrease abroad,* $\frac{dp_j}{d\theta_j} = \beta a \frac{p}{1-\theta} > 0$ *and* $\frac{dp_i}{d\theta_j} = -\beta\frac{1}{N-1}a\frac{p}{1-\theta} < 0$*.*

Proof Let us denote variables of the country under consideration by subscript A and use B to denote the other countries (which are ex-ante symmetric from the point of view of country A). First, we use $npq = \frac{\tau}{\beta}I$ in $(1-\beta)\int_0^M p(i)q(i)di = (1-\beta)Nnpq$ to obtain $(1-\beta)\int_0^M p(i)q(i)di = \frac{1-\beta}{\beta}\tau I^w$. Using this result, $p_A = \frac{(w_A)^\beta}{1-\theta_A}$ and $I^w = I_A + (N-1)I_B$ we can rewrite the balanced trade condition, $\tau I_A = \beta n(p_A)^{1-\varepsilon}[\tau I^w + (1-\beta)\int_0^M p(i)q(i)di]$, as:

$$w_A L = n\left(\frac{{w_A}^\beta}{1-\theta_A}\right)^{1-\varepsilon}[w_A L + (N-1)w_B L] \tag{5.35}$$

The price index can be represented as:

$$1 = n\left(\frac{{w_A}^\beta}{1-\theta_A}\right)^{1-\varepsilon} + (N-1)n\left(\frac{{w_B}^\beta}{1-\theta_B}\right)^{1-\varepsilon} \tag{5.36}$$

Total differentiation of (5.35) and (5.36) with respect to $\{w_A, w_B, \theta_A\}$, thereby taking θ_B, L_B and L_A as constant, gives us:

$$\frac{I_A}{w_A}dw_A = \frac{I_A}{I^w}(\frac{I_A}{w_A}dw_A + (N-1)\frac{I_B}{w_B}dw_B) + \beta(1-\varepsilon)\frac{I_A}{w_A}dw_A + (1-\varepsilon)\frac{I_A}{1-\theta_A}d\theta_A \tag{5.37}$$

$$0 = \beta\frac{L_A}{I^w}dw_A + \frac{1}{1-\theta_A}\frac{I_A}{I^w}d\theta_A + (N-1)\beta\frac{L_B}{I^w}dw_B \tag{5.38}$$

Rearranging (5.37) and noting that $L_B = L_A$ leads to:

$$dw_B = \frac{1}{(N-1)I_A}[(1+\beta(\varepsilon-1))I^w - I_A]dw_A - \frac{1}{N-1}\frac{1-\varepsilon}{1-\theta_A}\frac{I^w}{L_B}d\theta_A \tag{5.39}$$

Substitution of (5.39) into (5.38), evaluating in the symmetric equilibrium ($w_A = w_B$ and $\theta_A = \theta_B$) and rearranging terms then provides for the equilibrium solution:

$$\begin{aligned}\frac{dw_A}{d\theta_A} &= -\frac{1}{\beta}\frac{1}{N}\frac{1+\beta(\varepsilon-1)N}{1+\beta(\varepsilon-1)}p^0 \\ &= (\underbrace{-\frac{1}{\beta}}_{TFP}+\underbrace{\frac{1}{\beta}\frac{N-1}{N}\frac{1}{1+\beta(\varepsilon-1)}}_{ToT})p^0\end{aligned} \tag{5.40}$$

Substitution of $\frac{dw_A}{d\theta_A}$ in $\frac{dp_A}{d\theta_A} = \beta\frac{p_A}{w_A}\frac{dw_A}{d\theta_A} + \frac{p_A}{1-\theta_A}$ and applying symmetry yields $\frac{dp_A}{d\theta_A} = a\frac{p}{1-\theta}$. These results can also be used to derive the effect on wages and prices in other countries. First, rewrite (5.39):

$$\frac{dw_B}{d\theta_A} = \frac{(1+\beta(\varepsilon-1))I^w - I_A}{(N-1)I_A}\frac{dw_A}{d\theta_A} - \frac{1}{N-1}\frac{1-\varepsilon}{1-\theta_A}\frac{I^w}{L_B} \tag{5.41}$$

Second, substitution of (5.40) into (5.41) yields:

$$\frac{dw_B}{d\theta_A} = \frac{dp_B}{d\theta_A} = -\left(\frac{1}{\beta}\frac{1}{N}\frac{1}{1+\beta(\varepsilon-1)}\right)p^0 = -\frac{1}{N-1}ap^0 < 0$$

Recall that by definition we must have $\frac{dp_A}{d\theta_A} + (N-1)\frac{dp_B}{d\theta_B} = 0$, which tells us that the terms-of-trade effects work purely distributive (zero-sum). This completes the proof.

Result 2 *The terms-of-trade effect and the TFP effect are monotonically increasing in the so-called 'intermediate goods multiplier'* $\frac{1}{\beta} \in [0, \infty)$.

Proof Inspection of $\frac{dw_j}{d\theta_j}$ in (5.40) immediately shows that the TFP coefficient is proportional to $1/\beta$. With respect to the terms-of-trade coefficient u, differentiation shows that $\frac{da}{d(1/\beta)} = \frac{a}{1/\beta}(1 + \beta\frac{\varepsilon-1}{1+\beta(\varepsilon-1)}) > 0$. This completes the proof.

Result 3 *Terms-of-trade effects of stricter environmental policy are larger when the degree of decentralization increases,* $\frac{da}{dN} = \frac{d}{dN}(\frac{1}{\beta}\frac{N-1}{N}\varepsilon_P) = \frac{1}{\beta}\frac{1}{N^2}\varepsilon_P > 0$*. Stated otherwise, the beneficial terms-of-trade effect that lowers the costs of environmental policy is larger for small countries.*

Proof Inspection of $a - b = \left(\frac{1}{\beta}\frac{N-1}{N}\varepsilon_P - \frac{1}{\beta}\right)$ immediately shows the partial derivative $\frac{d(a-b)}{dN} = \frac{da}{N} = \frac{1}{\beta}\frac{1}{N^2}\varepsilon_P > 0$, indicating that terms-of-trade effects are larger when environmental policy is imposed from a more decentralized level (regulatory decoupling).

Result 4 *The effect of decentralization on the marginal benefits of meeting the domestic standard is ambiguous (*$\frac{\partial}{\partial N}(\Omega^B) \gtrless 0$*).*

From the definitions of $\bar{z}$, $\varepsilon_{z,\theta}$ and $\varepsilon^l_{z,\theta}$ we derive the following partial derivatives:

$$\frac{\partial\bar{z}}{\partial N} = -(1-\beta)\frac{\bar{z}}{N} + \frac{\bar{z}}{N} > 0 \quad , \quad \frac{\partial\varepsilon_{z,\theta}}{\partial N} = -(1-\beta)\frac{da}{dN} < 0 \quad , \quad \frac{\partial\varepsilon^l_{z,\theta}}{\partial N} = -\frac{\varepsilon^l_{z,\theta}}{N} < 0$$

$$\begin{aligned}\frac{\partial(\varepsilon_{z,\theta}+(N-1)\varepsilon^l_{z,\theta})}{\partial N} &= -(1-\beta)\frac{da}{dN}+\varepsilon^l_{z,\theta}-(N-1)\frac{\varepsilon^l_{z,\theta}}{N}\\ &= \frac{1}{\beta}\frac{1-\beta}{\beta}\frac{1}{N^2}\left((1-2\beta)\varepsilon_P-1\right)<0\end{aligned}$$

Differentating Ω^B (see definition 1) with respect to N and using these partial derivatives shows us that

$$\frac{\partial}{\partial N}(\Omega^B)=-\frac{\Omega^B}{N}+\frac{\Omega^B}{\varepsilon_{z,\theta}+(N-1)\varepsilon^l_{z,\theta}}\left(\frac{d\varepsilon_{z,\theta}}{dN}+\varepsilon^l_{z,\theta}+(N-1)\frac{d\varepsilon^l_{z,\theta}}{dN}\right)+\frac{\Omega^B}{\bar{z}}\frac{d\bar{z}}{dN}\gtreqless 0.$$

This completes the proof.

Result 5 *If the intensity of trade is endogenous then*

(i) a higher standard will impact the wage rate in the mitigating country through an ambiguous trade volume effect, next to the standard TFP effect and terms-of-trade effect.

(ii) Prices and wages in other countries are again affected by negative terms-of-trade spillovers, but also by an ambiguous trade volume effect as well as a negative production efficiency effect.

Proof Follows immediately from inspection of equations (5.33)-(5.34) where the volume-of-trade effects are novel compared to previous sections.

Proposition 1 *An increase in the stringency of environmental policy:*

1) reduces pollution at home, that is, $\frac{dz_j}{d\theta_j}=-\varepsilon_{z,\theta}\frac{z}{1-\theta}<0$.

2) causes negative (carbon) leakage, $\frac{dz_i}{d\theta_j}=-\varepsilon^l_{z,\theta}\frac{z}{1-\theta}<0$ *if and only if* $\beta<1$. *There is zero leakage* $(\frac{dz_i}{d\theta_j}=0)$ *if there is no IO-structure* $(\beta=1)$.

Proof (1) Differentiation of (5.22) with respect to θ_A, w_A and w_B leads to

$$\begin{aligned}\frac{dz_A}{d\theta_A} &= z_A\frac{e'(\theta_A)}{e(\theta_A)}-z_A\frac{1}{1-\theta_A}+z_A\frac{1-\beta}{\beta}\frac{1}{\lambda_A}\frac{d\lambda_A}{d\theta_A}-z_A\frac{1-\beta}{\beta}\frac{1}{G}n(1-\theta_A)^{-\frac{1}{\varepsilon}}G^{\frac{1}{\varepsilon}}\\ &\quad +z_A\frac{1-\beta}{\beta}\frac{1}{G}n(N-1)(1-\theta_B)^{\frac{\varepsilon-1}{\varepsilon}}\left(\frac{\lambda_B}{\lambda_A}\right)^{\frac{(\varepsilon-1)(1-\beta)-\varepsilon}{\varepsilon}}(1-\beta)G^{\frac{1}{\varepsilon}}\frac{d}{d\theta_A}\left(\frac{\lambda_B}{\lambda_A}\right)\end{aligned}$$

Substitution of $\frac{d\lambda_A}{d\theta_A}=\lambda_A(\frac{1}{w_A}\frac{dw_A}{d\theta}-\frac{1}{w_A+(N-1)w_B}(\frac{dw_A}{d\theta_A}+(N-1)\frac{dw_B}{d\theta_A}))$ and $\frac{d}{d\theta_A}(\frac{\lambda_B}{\lambda_A})=\frac{1}{w}(\frac{dw_B}{d\theta_A}-\frac{dw_A}{d\theta_A})$, using result 1, applying symmetry and using the definition $\varepsilon_{z,\theta}$ then provides us with $\frac{dz_j}{d\theta_j}=-\varepsilon_{z,\theta}\frac{z}{1-\theta}<0$. (2) Similar to (1), differentiate z_B from (5.22) with respect to θ_A, w_A and w_B which gives us $\frac{dz_B}{d\theta_A}=\frac{1-\beta}{\beta}\frac{z_B}{G_B}\frac{dG_B}{d\theta_A}$. Next, substitute $\frac{dG_B}{d\theta_A}=\frac{\left(-1+(1-\beta)(1-\theta_A)(\frac{\lambda_A}{\lambda_B})^{-1}\frac{d}{d\theta_A}(\frac{\lambda_A}{\lambda_B})\right)}{n(1-\theta_A)^{\frac{1}{\varepsilon}}(\frac{\lambda_B}{\lambda_A})^{\frac{(\varepsilon-1)(1-\beta)}{\varepsilon}}}(G_B)^{\frac{1}{\varepsilon}}$, apply symmetry and use the definition of $\varepsilon^l_{z,\theta}$ to obtain $\frac{dz_i}{d\theta_j}=-\varepsilon^l_{z,\theta}\frac{z}{1-\theta}<0$. This completes the proof.

Proposition 2

(i) Under transboundary pollution ($\phi>0$*) we find* $\theta^S\gtreqless\theta^{NC}\Leftrightarrow 1\gtreqless\frac{1+\phi(N-1)}{\phi(N-1)}\frac{N-1}{N}\frac{1}{1+\beta(\varepsilon-1)}$.

(ii) Under local pollution ($\phi=0$*) we have* $\theta^S<\theta^{NC}$ *for all* $N>1$.

(iii) There exists a unique $\bar{\phi}\equiv\frac{1}{N-1}\frac{a}{b-a}\in[0,1]$ *such that* $\theta^S\gtreqless\theta^{NC}$ *for all* $\phi\gtreqless\bar{\phi}$. *This threshold* $\bar{\phi}$ *is decreasing in* β.

Proof (i) Substitution of the coefficients from definition 1 into (5.28) results in the following expressions for the pollution standard:

$$\theta^{NC} = 1 - \left[\frac{\tau(b-a)}{\eta n(\varepsilon_{z,\theta} + (N-1)\varepsilon^l_{z,\theta})\bar{z}} \right]^{\frac{1}{\Phi}} \tag{5.42}$$

$$\theta^{S} = 1 - \left[\frac{1}{1+\phi(N-1)} \frac{\tau b}{\eta n(\varepsilon_{z,\theta} + (N-1)\varepsilon^l_{z,\theta})\bar{z}} \right]^{\frac{1}{\Phi}} \tag{5.43}$$

where $\Phi \equiv \frac{(1-\alpha)\beta+\alpha-\alpha(1-\tau)(1-\sigma)}{\alpha\beta} > 0$. Comparing these solutions shows us that $\theta^S \gtrless \theta^{NC} \Leftrightarrow \tau(b-a) \gtrless \frac{\tau b}{1+\phi(N-1)} \Leftrightarrow 1 \gtrless \frac{1+\phi(N-1)}{\phi(N-1)} \frac{N-1}{N} \frac{1}{1+\beta(\varepsilon-1)}$. With $\phi = 1$ this expression reads $\theta^S \gtrless \theta^{NC} \Leftrightarrow 1 \gtrless \frac{1}{1+\beta(\varepsilon-1)}$ and thus $\theta^S > \theta^{NC}$. (ii) If there are no spillovers, we can obtain the non-cooperative solution from (5.42) by setting $\phi = 0$ such that the closed-form solution is now given by $\theta^{NC}|_{\phi=0} = 1 - \left[\frac{\tau(b-a)}{\eta n(\varepsilon_{z,\theta}+(N-1)\varepsilon^l_{z,\theta})\bar{z}} \right]^{\frac{1}{\Phi}}$ and likewise for the social optimum from (5.43), $\theta^S|_{\phi=0} = 1 - \left[\frac{\tau b}{\eta n(\varepsilon_{z,\theta}+(N-1)\varepsilon^l_{z,\theta})\bar{z}} \right]^{\frac{1}{\Phi}}$. Quick inspection of these equations shows us that $\theta^S < \theta^{NC}$ since $a > 0$ for all $N > 1$. (iii) From (i) we find that $\bar{\phi}$ is implicitly defined by $\theta^S = \theta^{NC}$. Rearranging leads to an explicit expression, $\bar{\phi} \equiv \frac{1}{N-1} \frac{a}{b-a}$. Differentiation with respect to β reveals that $\frac{d\bar{\phi}}{d\beta} = \left(\frac{\frac{\partial a}{\partial \beta} \frac{b}{a} - \frac{\partial b}{\partial \beta}}{b-a} \right) \bar{\phi} < 0$. This completes the proof.

Proposition 3 (i) *Global welfare in the social optimum is always higher than in the non-cooperative equilibrium unless $\phi = \bar{\phi}$; in this case global welfare in the social optimum and non-cooperative equilibrium coincide. (ii) For $\phi < (>)\bar{\phi}$ we find that green welfare is higher (lower) in the non-cooperative equilibrium than in the social optimum.*

(i) By definition we must have that global welfare is (strictly) higher in the social optimum than in the non-cooperative equilibrium, that is, $V^w(\theta^S) \geq V^w(\theta^{NC})$. From proposition 1 we have $\theta^S \neq \theta^{NC}$ unless $\phi = \bar{\phi}$ and therefore $V^w(\theta^S) > V^w(\theta^{NC})$ for all $\phi \neq \bar{\phi}$. (ii) Since $\theta^S \gtreqless \theta^{NC}$ for $\phi \gtreqless \bar{\phi}$ we have $Z(\theta^S) \gtreqless Z(\theta^{NC})$ for $\phi \gtreqless \bar{\phi}$. This completes the proof.

Proposition 4 (*Desensitisation of pollution with respect to local environmental policy). Under decentralization*

(i) *pollution in any given country becomes less responsive to local environmental policy* ($\frac{\partial \varepsilon_{z,\theta}}{\partial N} < 0$ *and* $\frac{\partial \varepsilon^l_{z,\theta}}{\partial N} < 0$)

(ii) *total foreign pollution becomes more responsive to local environmental policy* ($\frac{\partial[(N-1)\varepsilon^l_{z,\theta}]}{\partial N} > 0$)

(iii) *the responsiveness of global pollution is negative* ($\frac{\partial(\varepsilon_{z,\theta}+(N-1)\varepsilon^l_{z,\theta})}{\partial N} < 0$).

Proof Differentiation of $\varepsilon_{z,\theta}$ and $(N-1)\varepsilon^l_{z,\theta}$ with respect to N immediately shows us that $\frac{\partial \varepsilon_{z,\theta}}{\partial N} = -(1-\beta)\frac{da}{dN} < 0$, $\frac{\partial \varepsilon^l_{z,\theta}}{\partial N} = -\frac{\varepsilon^l_{z,\theta}}{N} < 0$ and $\frac{\partial[(N-1)\varepsilon^l_{z,\theta}]}{\partial N} = \frac{1}{N}\varepsilon^l_{z,\theta} > 0$. This proofs (i) and (ii). Using these derivatives one can show that $\frac{\partial(\varepsilon_{z,\theta}+(N-1)\varepsilon^l_{z,\theta})}{\partial N} = -(1-\beta)\frac{da}{dN} + \frac{1}{N}\varepsilon^l_{z,\theta} = \frac{1}{\beta}\frac{1-\beta}{\beta}\frac{1}{N^2}\left((1-2\beta)\varepsilon_P - 1\right) < 0$. This completes the proof.

Proposition 5 *(i) International factor ownership has an ambiguous effect on the non-cooperative standard and an ambiguous effect on global environmental quality.*

(ii) There exists a unique $\bar{\phi}_O \equiv \frac{1}{N-1}\frac{\tau b-\Omega_O^C}{\Omega_O^C} \in [0,1]$ *such that* $\theta_O^S \gtrless \theta_O^{NC}$ *for all* $\phi \gtrless \bar{\phi}_O$. *This threshold* $\bar{\phi}_O$ *is decreasing in* β *and ambiguous in* δ *and ambiguous in* h.

Proof. (i) From $MB = MAC$ and lemma 2 we directly obtain $\theta_O^{NC} = 1 - \left[\frac{\Omega_O^C}{\Omega_O^B}\right]^{\frac{1}{\Phi}}$. Taking derivatives, $\frac{\partial}{\partial\delta}(\theta_O^{NC}) = -\frac{1}{\Phi}\left[\frac{\Omega_O^C}{\Omega_O^B}\right]^{\frac{1}{\Phi}-1}\left(\frac{\partial\Omega_O^C}{\partial\delta} - \frac{\partial\Omega_O^B}{\partial\delta}\right) \gtrless 0$. Since pollution is monotonically decreasing in θ_O^{NC} the effect on global environmental quality is ambiguous. (ii) From $\theta_O^S = \theta_O^{NC}$ we derive $\Omega_O^C[1 + \phi(N-1)] = \Omega_S^C = \tau b$. After rearranging we obtain the result in the main text. Differentiation shows $\frac{\partial\bar{\phi}_O}{\partial\beta} < 0$, $\frac{\partial\bar{\phi}_O}{\partial\delta} \gtrless 0$ and $\frac{\partial\bar{\phi}_O}{\partial h} \gtrless 0$.

5.9.2 Derivations

Derivation of the Balanced Trade Condition

(1) Direct Method

Three steps are needed. First, using (5.2) profit maximization in the intermediate goods sector results in:

$$w_j l_{jy} = \beta p_j y_j \quad \text{and} \quad x_{jy} = (1-\beta)p_j y_j \tag{5.44}$$

Second, profit maximization in the final goods sector gives us $w_j L_{jC} = (1-\tau)I_j$. Using this result, the definition of nominal income $I_j = w_j L = p_{jC}C$ and (5.10) we obtain

$$n w_j l_{jy} = \tau I_j \tag{5.45}$$

Combining (5.44) and (5.45) then provides us with expressions for l_{jy} and x_{jy} as function of parameters and domestic income, $l_{jy} = \frac{\tau I_j}{n w_j}$ and $x_{jy} = (\frac{1-\beta}{\beta})\frac{\tau I_j}{n}$, as well as being able to rewrite $\sum_{j=1}^{j=N} n p_j q_j = \sum_{j=1}^{j=N} \frac{\tau}{\beta} I_j = \frac{\tau}{\beta} I^w$. Third, we then substitute $l_{jy} = \frac{\tau I_j}{n w_j}$ and $x_{jy} = (\frac{1-\beta}{\beta})\frac{\tau I_j}{n}$ into $q_j = (1-\theta_j)(l_{jy})^\beta (x_{jy})^{1-\beta}$, which in turn we substitute for q_j on the left-hand side of the demand function (5.11) and finally we rearrange to get:

$$I_j = n(p_j)^{1-\varepsilon} I^w$$

which equals (5.14) in the main text.

(2) Alternative Method

Setting imports (5.12) equal to exports (5.13), we can write

$$n p_j y_j - n p_j y_{jj} = \sum_i n p_i y_{ij} - n p_j y_{jj}$$

On the left-hand side we can substitute for $np_j y_j = np_j^{1-\varepsilon}\frac{\tau}{\beta}I^w$ and $np_j y_{jj} = np_j y_j \frac{X_j}{X^w} = np_j^{1-\varepsilon}\frac{\tau}{\beta}I_j$:

$$EX_j = np_j y_j - np_j y_{jj} = np_j^{1-\varepsilon}\frac{\tau}{\beta}(1-\frac{I_j}{I^w})I^w$$

On the right-hand side we can substitute for $\sum_i np_i y_{ij} = \frac{\tau}{\beta}I_j$ and $np_j y_{jj} = \frac{\tau}{\beta}I_j\frac{I_j}{I^w}$:

$$IM_j = \sum_i np_i y_{ij} - np_j y_{jj} = \frac{\tau}{\beta}I_j(1-\frac{I_j}{I^w})$$

Equating imports and export results in the equation obtained in the main text, $I_j = np_j^{1-\varepsilon}I^w$.

Production of the Composite Intermediate Good

Define λ_j as a country's consumption share / import share of a typical intermediate good, that is, $\lambda_j \equiv \frac{y_{ij}}{y_i}$ for all i, j. Total demand for an intermediate good y_i follows from the balanced trade condition (5.14), $y_i = p_i^{-\varepsilon}\frac{\tau}{\beta}I^w$. Demand for intermediate i by country j is given by $y_{ij} = p_i^{-\varepsilon}X_j = y_{ij} = p_i^{-\varepsilon}\frac{\tau}{\beta}I_j$, where the second equality follows from $X_j = X_{jy} + X_{jC} = \frac{1-\beta}{\beta}\tau I_j + \tau I_j = \frac{\tau}{\beta}I_j$. These two results can then be used to derive the following intermediate result:

$$\lambda_j = \frac{y_{ij}}{y_i} = \frac{p_i^{-\varepsilon}X_j}{p_i^{-\varepsilon}\frac{\tau}{\beta}I^w} = \frac{I_j}{I^w} \tag{5.46}$$

Next, we substitute for $y_{ij} = \lambda_j y_i$ in (5.4) to obtain $X_j = nx_j = \lambda_j(\sum_i ny_i^{\frac{\varepsilon-1}{\varepsilon}})^{\frac{\varepsilon}{\varepsilon-1}}$. Then we substitute for all y_i from (5.2) in this result:

$$X_j = (\lambda_j)^{\frac{1}{\beta}}(\frac{1-\beta}{n})^{\frac{1-\beta}{\beta}}\left((\sum_i n((1-\theta_i)(\frac{\lambda_i}{\lambda_j})^{1-\beta})^{\frac{\varepsilon-1}{\varepsilon}})^{\frac{\varepsilon}{\varepsilon-1}}\right)^{\frac{1}{\beta}} l_y$$

which determines X_j as a function of import shares and environmental policies.

Equilibrium pollution and IO-linkages

In equilibrium world pollution can be written as $Z^w = Nnz = Nn\bar{z}(1-\theta^{NC})^{\Phi}$. Total differentiation of this equation with respect to β then shows:

$$\frac{\partial Z^w}{\partial\beta} = \frac{Z^w}{\bar{z}}\frac{\partial\bar{z}}{\partial\beta} - \Phi\frac{Z^w}{1-\theta^{NC}}\frac{\partial\theta^{NC}}{\partial\beta} - \frac{1}{\beta^2}Z^w\log[(1-\theta^{NC})] \gtrless 0$$

where the first two terms are ambiguous but the last term is positive provided the standard is positive. A change in the input-output structure of the world economy, as captured by the parameter β, affects world pollution through three different channels. The first term represents an ambiguous effect resulting from various productivity and allocation effects. Most likely this effect is negative : if β increases then the international input-output structure of production is weakened, effectively reducing the productivity of intermediate goods production in all other countries. The second effect works through the non-cooperative standard and also has an ambiguous impact on global pollution. Essentially, the second term is also a productivity effect; strengthening the input-output structure increases (or decreases) the non-cooperative standard, which again lowers (or increases) productivity in the intermediate goods sector. The third term states that a change in the input-output structure has an impact on the elasticity of world pollution with respect to environmental policy, that is, $\Phi = \frac{dZ^w}{d(1-\theta^{NC})}\frac{1-\theta^{NC}}{Z^w} > 0$. A higher β weakens the IO-structure, increases the elasticity Φ and lowers global pollution.

Marginal Cost of Meeting a Standard under International Factor Ownership

Under international factor ownership the marginal cost of meeting a standard is given by:

$$\frac{1}{c_j}\frac{dc_j}{d\theta_j} = \begin{array}{c} \frac{1}{w_j^{1-\tau}}\frac{(1-\delta)}{c_j}\frac{dw_j}{d\theta_j} + \frac{1}{w_j^{1-\tau}}\frac{h\frac{1}{N-1}\delta}{c_j}\sum_{i\neq j}\frac{dw_i}{d\theta_j} \\ -\frac{1-\tau}{c_j}w_j^{-\tau}\frac{1}{w_j^{1-\tau}}c_j\frac{dw_j}{d\theta_j} + \frac{\tau}{c_j}(1-h)\frac{1}{N-1}\delta\sum_{i\neq j}\frac{dw_i}{d\theta_j}w_i^{\tau-1} \end{array} \tag{5.47}$$

where we used the new equation for c_j as shown in the main text. The right-hand side of (5.47) now consists of four different terms (for their interpretation see the main text).

The Balanced Trade Condition and Comparative Statics under International Factor Ownership

Note that $[I_j^d - (1-\tau)I_j^c]$ on the left-hand side of (5.29) follows from (i) the definition of gross domestic income, $I_j^d = w_jL_{jC} + nw_jl_{jy}$, and (ii) the expenditure share of labor in the final goods sector, $w_jL_{jC} = (1-\tau)I_j^c$, which is acquired from profit maximization in the final goods sector. Combining (i) and (ii), and using $\beta np_jq_j = nw_jl_{jy}$, results in $\beta np_jq_j = I_j^d - (1-\tau)I_j^c$. Substitution of this result in the demand equation, $np_jq_j = n(p_j)^{1-\varepsilon}[\tau I^w + (\frac{1-\beta}{\beta})\tau I^w]$, and multiplying with β on both sides immediately gives (5.29). The price index equation remains the same, see (5.6). Again, let us denote variables of the country under consideration by subscript A and use B to denote the other countries. We differentiate (5.6) and (5.29) to obtain the following set of equations:

$$0 = \beta\frac{1}{I^w}\frac{I_A^d - (1-\tau)I_A^c}{w_A}dw_A + \frac{1}{I^w}\frac{I_A^d - (1-\tau)I_A^c}{1-\theta_A}d\theta_A + (N-1)\beta\frac{1}{I^w}\frac{I_A^d - (1-\tau)I_A^c}{w_B}dw_B$$

$$\begin{aligned} &Ldw_A - (1-\tau)(1-\delta+(1-h)\delta)Ldw_A - (1-\tau)h\delta Ldw_B = \\ &(1-\varepsilon)\beta\frac{I_A^d - (1-\tau)I_A^c}{w_A}dw_A + (1-\varepsilon)\frac{I_A^d - (1-\tau)I_A^c}{1-\theta_A}d\theta_A \\ &+[(1-\beta)+1]\frac{1}{E}\frac{I_A^d - (1-\tau)I_A^c}{1}[Ldw_A + (N-1)Ldw_B] \end{aligned}$$

Rearranging the differentiated balanced trade condition leads to:

$$[(1-\tau)h\delta+\tau\frac{1}{E}(I_A^d-(1-\tau)I_A^c)(N-1)]Ldw_B=[L-(1-\tau)(1-\delta+(1-h)\delta)L$$
$$-(1-\varepsilon)\beta\frac{I_A^d-(1-\tau)I_A^c}{w_A}-\tau\frac{1}{E}(I_A^d-(1-\tau)I_A^c)L]dw_A$$
$$-[(1-\varepsilon)\frac{I_A^d-(1-\tau)I_A^c}{1-\theta_A}]d\theta_A$$

We then simplify notation as follows:

$$0=\theta_1dw_A+\theta_2d\theta_A+\theta_3dw_B$$

$$dw_B=\frac{\Delta_1}{\Delta_2}dw_A-\frac{\Delta_3}{\Delta_2}d\theta_A$$

Examination of these individual terms shows us:

$$\theta_3\frac{\Delta_3}{\Delta_2}=\frac{N-1}{N}\beta\frac{1}{w_B}\frac{(1-\varepsilon)\frac{1}{1-\theta_A}I_A}{(1-\tau)h\delta L+\tau\frac{N-1}{N}L}=\frac{N-1}{N}\beta\frac{(1-\varepsilon)\frac{1}{1-\theta_A}}{[(1-\tau)h\delta+\tau\frac{N-1}{N}]}$$

$$\theta_3\frac{\Delta_1}{\Delta_2}=\frac{N-1}{N}\beta\frac{1}{w_B}\frac{L-(1-\tau)(1-\delta+(1-h)\delta)L-(1-\varepsilon)\beta\frac{\tau I_A}{w_A}-\tau\frac{1}{N}L}{(1-\tau)h\delta L+\tau\frac{N-1}{N}L}$$

$$\theta_2-\theta_3\frac{\Delta_3}{\Delta_2}=\frac{1}{N}\frac{1}{1-\theta_A}-[\frac{N-1}{N}\beta\frac{(1-\varepsilon)\tau\frac{1}{1-\theta_A}}{(1-\tau)h\delta+\tau\frac{N-1}{N}}]$$

$$\theta_1+\theta_3\frac{\Delta_1}{\Delta_2}=\beta\frac{1}{N}\frac{1}{w_A}+[\frac{N-1}{N}\beta\frac{1}{w_B}][\frac{L-(1-\tau)(1-\delta+(1-h)\delta)L-(1-\varepsilon)\beta\frac{\tau I_A}{w_A}-\tau\frac{1}{N}L}{(1-\tau)h\delta L+\tau\frac{N-1}{N}L}]$$

Substitution of these terms into the solution $-\frac{dw_A}{d\theta_A}=\frac{\theta_2-\theta_3\frac{\Delta_3}{\Delta_2}}{\theta_1+\theta_3\frac{\Delta_1}{\Delta_2}}$ then gives the results as shown in the main text:

$$-\frac{dw_A}{d\theta_A}=\frac{1}{\beta}\frac{(1-\tau)h\delta+\tau(\frac{N-1}{N})+[(N-1)\beta(\varepsilon-1)\tau]}{(1-\tau)h\delta+\tau(\frac{N-1}{N})+[(N-1)][1-(1-\tau)(1-h\delta)+\tau(\varepsilon-1)\beta-\tau\frac{1}{N}]}p$$

Rewriting shows more clearly the various effects:

$$\frac{dw_A}{d\theta_A}=\underbrace{\left(-p+\frac{1}{\varepsilon}p\right)\left(1+\frac{\tau(N-1)(1-\beta)(\varepsilon-1)-N(1-\tau)h\delta}{N(1-\tau)h\delta+(N-1)\tau(1+\beta(\varepsilon-1))}\right)}_{\text{small open economy}}$$
$$-\frac{1}{N}\frac{1}{\beta}\frac{1}{\varepsilon}p\left(\frac{\tau(N-1)\varepsilon}{N(1-\tau)h\delta+(N-1)\tau(1+\beta(\varepsilon-1)}\right)$$

or

$$\frac{dw_A}{d\theta_A}=(a_O-b)p^0$$

where $a_O \equiv \frac{1}{\beta}\frac{N-1}{N}\frac{N(1-\tau)\delta+(N-1)\tau}{N(1-\tau)\delta+(N-1)\tau(1+\beta(\varepsilon-1))}$. This result can also be used to derive the effect on wages in other countries by substitution of $\frac{dw_A}{d\theta_A}$:

$$\frac{dw_B}{d\theta_A} = \frac{dp_B}{d\theta_A} = \frac{(1-\tau)h\delta + \tau[1+\beta(\varepsilon-1)] - \tau\frac{1}{N}}{(1-\tau)h\delta + \tau\frac{N-1}{N}}\frac{dw_A}{d\theta_A} + \frac{(\varepsilon-1)\tau}{(1-\tau)h\delta + \tau(\frac{N-1}{N})}p$$

After substitution we retrieve:

$$\frac{dw_B}{d\theta_A} = \frac{dp_B}{d\theta_A} = g(a_O - b)p^0 + dp^0 = [g - \frac{1}{\beta a_O}]a_O p$$

where $g \equiv \frac{(1-\tau)h\delta+\tau[1+\beta(\varepsilon-1)]-\tau\frac{1}{N}}{(1-\tau)h\delta+\tau\frac{N-1}{N}} > 0$ and $d \equiv \frac{(\varepsilon-1)\tau}{(1-\tau)h\delta+\tau(\frac{N-1}{N})}$. Further rearranging then shows that

$$\begin{aligned}\frac{dw_B}{d\theta_A} &= g(a_O - b)p^0 + dp^0 \\ &= -\frac{1}{N-1}a_O p^0 + [(N-1)g + 1 + (N-1)\frac{d-gb}{a_O}]\frac{1}{N-1}a_O p^0\end{aligned}$$

where it can be shown that $(N-1)g+1+(N-1)\frac{d-gb}{a_O} = N\frac{\Delta+(N-1)\tau\beta(\varepsilon-1)}{\Delta} - N\frac{\Delta+(N-1)\tau\beta(\varepsilon-1)}{\Delta} = 0$ where $\Delta \equiv N(1-\tau)h\delta + \tau(N-1)$. Thus we conclude

$$\frac{dw_B}{d\theta_A} = \frac{dp_B}{d\theta_A} = -\frac{1}{N-1}a_O p$$

which again shows that there are only terms-of-trade spillovers.

The Balanced Trade Condition and Comparative Statics under Endogenous Openness

First, from profit maximization and (5.2) it follows that $w_j l_{jy} = \beta p_j y_j$ and $x_{jy} = (1-\beta)p_j y_j$. Second, cost minimization in the final goods sector gives us $w_j L_{jC} = (1-\tau)^\xi(\frac{w}{p_C})^{1-\xi}I_j$ and $nw_j l_{jy} = wL - wL_C = [1-(1-\tau)^\xi(\frac{w}{p_C})^{1-\xi}]I_j$ and subsequently $np_j y_j = \frac{1}{\beta}[1-(1-\tau)^\xi(\frac{w}{p_C})^{1-\xi}]I_j$. Combining these two results then provides us with $l_{jy} = \frac{[1-(1-\tau)^\xi(\frac{w}{p_C})^{1-\xi}]I_j}{nw_j}$ and $x_{jy} = (\frac{1-\beta}{\beta})\frac{1}{n}[1-(1-\tau)^\xi(\frac{w}{p_C})^{1-\xi}]I_j$. These results are then substituted into $q_j = (1-\theta_j)(l_{jy})^\beta(x_{jy})^{1-\beta}$, which in turn is substituted for q_j on the left-hand side of the demand function (5.11) to get:

$$\left[1-(1-\tau)^\xi(\frac{w_j}{p_{jC}})^{1-\xi}\right]I_j = \beta n(p_j)^{1-\varepsilon}\left[\tau^\xi\left(\sum_{i=1}^{N}(p_{iC})^{\xi-1}I_i\right) + \frac{1-\beta}{\beta}\tau I^w\right] \quad (5.48)$$

where the right-hand side was derived by using $E = \tau^\xi\left(\sum_{i=1}^N X_{iC}\right) + (1-\beta)\int_0^M p(i)q(i)di$, $X_{iC} = \tau^\xi(p_{iC})^{\xi-1}I_i$ and $(1-\beta)\int_0^M p(i)q(i)di = \frac{1-\beta}{\beta}\tau I^w$. So here $\tau^\xi(p_C)^{\xi-1}$ denotes the fraction of expenditures in the final goods sector that is spent on intermediates goods and which equals τ in case $\xi = 1$.

Next, we substitute for $I^w = I_A + (N-1)I_B$ to obtain:

$$\left[1-(1-\tau)^{\xi}(w_A^{\tau})^{1-\xi}\right] I_A =$$
$$\beta n(\frac{w_A^{\beta}}{1-\theta_A})^{1-\varepsilon}\left[\tau^{\xi}\left(\sum_{i=1}^{N}(w_i^{1-\tau})^{\xi-1}I_i\right)+\frac{1-\beta}{\beta}\tau(I_A+(N-1)I_B)\right]$$

Differentiating this new balanced trade condition leads to:

$$\left[1-(1-\tau)^{\xi}(w_A^{\tau})^{1-\xi}\right]\frac{I_A}{w_A}dw_A-\tau(1-\xi)(1-\tau)^{\xi}(w_A)^{\tau(1-\xi)-1}I_A dw_A=$$
$$\left[1-(1-\tau)^{\xi}(w_A^{\tau})^{1-\xi}\right]\frac{I_A}{E}\frac{1-\beta}{\beta}\tau(\frac{I_A}{w_A}dw_A+(N-1)\frac{I_B}{w_B}dw_B)$$
$$+\beta(1-\varepsilon)\frac{\left[1-(1-\tau)^{\xi}(w_A^{\tau})^{1-\xi}\right]I_A}{w_A}dw_A$$
$$+(1-\varepsilon)\frac{\left[1-(1-\tau)^{\xi}(w_A^{\tau})^{1-\xi}\right]I_A}{1-\theta_A}d\theta_A+\left[1-(1-\tau)^{\xi}(w_A^{\tau})^{1-\xi}\right]\frac{I_A}{E}D$$

where

$$\begin{aligned} D &\equiv \tau^{\xi}[(1-\tau)(\xi-1)w_A^{(1-\tau)(\xi-1)-1}I_A dw_A+w_A^{(1-\tau)(\xi-1)}\frac{I_A}{w_A}dw_A \\ &\quad +(N-1)[(1-\tau)(\xi-1)w_B^{(1-\tau)(\xi-1)-1}I_B dw_B+w_B^{(1-\tau)(\xi-1)}\frac{I_B}{w_B}dw_B]] \\ &= F dw_A+(N-1)G dw_B \end{aligned}$$

Rearranging this new differentiated BT condition gives an expression for w_B:

$$dw_B = \frac{[1+\epsilon_{Ly}^w-\frac{I_A}{E}\frac{1-\beta}{\beta}\tau+\beta(\varepsilon-1)-\frac{w_A}{E}F]}{\left(\frac{I_A}{E}\frac{1-\beta}{\beta}\tau(N-1)+\frac{w_A}{E}(N-1)G\right)}dw_A \quad (5.49)$$
$$+\frac{(\varepsilon-1)p^0}{\left(\frac{I_A}{E}\frac{1-\beta}{\beta}\tau(N-1)+\frac{w_A}{E}(N-1)G\right)}d\theta_A \quad (5.50)$$

Substitution of this expression into the differentiated price index condition (5.38) and rearranging:

$$\frac{dw_A}{d\theta_A}=-\frac{(\varepsilon-1)+\frac{1}{\beta}\frac{1}{N}+\frac{1}{\beta}\frac{1}{N}\epsilon_v^w}{1+\beta(\varepsilon-1)+\epsilon_{Ly}^w}p^0$$

where $\epsilon_v^w \equiv \frac{dv}{dw}\frac{w}{v} = \frac{\tau^{\xi}(1-\tau)(\xi-1)w^{(1-\tau)(\xi-1)}}{\tau^{\xi}w^{(1-\tau)(\xi-1)}+\frac{1-\beta}{\beta}\tau} \gtrless 0$ for $\xi \gtrless 1$ and $\epsilon_{Ly}^w \equiv \frac{ds_L^T}{dw}\frac{w}{s_L^T} = \tau(\xi-1)(1-\tau)^{\xi}\left(\frac{(w_A)^{\tau(1-\xi)}}{1-(1-\tau)^{\xi}(w_A^{\tau})^{1-\xi}}\right) \gtrless 0$ for $\xi \gtrless 1$. Compare the solution with the standard solution and rewrite to observe an additional negative trade-volume effect that results from environmental policy:

$$\frac{dw_A}{d\theta_A}=(\underbrace{-\frac{1}{\beta}}_{\text{TFP effect}}+\underbrace{\frac{1}{\beta}\frac{N-1}{N}\frac{1}{1+\beta(\varepsilon-1)+\epsilon_{Ly}^w}}_{\text{ToT effect}}-\underbrace{\frac{1}{\beta}\frac{1}{N}\frac{(\epsilon_v^w-N\epsilon_{Ly}^w)}{1+\beta(\varepsilon-1)+\epsilon_{Ly}^w}}_{\text{Trade-Volume effect}})p^0$$

where the last term can be negative or positive. Substitution of $\frac{dw_A}{d\theta_A}$ in (5.49) then gives us the cross-derivative:

$$\frac{dw_B}{d\theta_A} = -\frac{1}{N-1}(\underbrace{\frac{1}{\beta}\frac{N-1}{N}\frac{1}{1+\beta(\varepsilon-1)+\epsilon_{Ly}^w}}_{\text{ToT effect}} \underbrace{-\frac{1}{\beta}\frac{1}{N}\frac{(\epsilon_v^w - N\epsilon_{Ly}^w)}{1+\beta(\varepsilon-1)+\epsilon_{Ly}^w}}_{\text{Trade-Volume effect}} + S(\theta))p^0$$

where $S(\theta) \equiv \frac{1}{\beta}\frac{1+\epsilon_{Ly}^w}{1+\epsilon_v^w} - \frac{1}{\beta}\frac{\varepsilon+\epsilon_{Ly}^w}{1+\beta(\varepsilon-1)+\epsilon_{Ly}^w}$.

Chapter 6

On Trade, Sustainable Development and Overlapping Kuznets Curves

6.1 Introduction

The claim that pollution rises at low levels of income while decreasing again at high levels of income is arguably one of the most debated topics in the field of environmental economics. The literature on this so-called environmental Kuznets curve (EKC) was initiated by the seminal article by Grossman and Krueger (1994). Many local pollutants, such as sulfurdioxide, lead, nitrogen oxide, DDT etc. seem to follow this pattern, but the evidence is far less compelling or even absent for most global pollutants such as carbon emissions, for natural resource use and biodiversity conservation. While empirical work has contributed much, both in terms of our understanding and by providing focus to future research efforts, so have theoretical inquiries. Many theoretical papers are part of an enormous literature that analyzes the complicated relationship between growth and the environment. As Levinson (2008) and Brock and Taylor (2005) note, the common approach here is to explain the occurrence of an EKC as a by-product of transition towards a balanced growth path with sustainable development. At low levels of income, the opportunity costs of abatement are large and citizens are willing to trade environmental degradation for income gains. Over time, with income per capita still rising, the marginal rate of substitution between consumption and pollution increases, thereby spurring abatement efforts. Eventually, pollution will start to decline with income.[2]

Surprisingly, there is hardly any attention for this topic in the context of open economies. Some may find this strange, since the EKC is essentially a story of economic development as well, and trade is often an important ingredient in any attempt to tell such a story. In addition, it is well known that empirical predictions derived from regressions based on closed economy models can deliver a faulty or incomplete picture (Matsuyama, 2008). The contribution of this chapter is threefold. First, we consider the idea of a global environmental Kuznets curve, i.e. the occurrence of an inverted u-shape for *world* pollution.

[1] In the sense that 'what comes up must come down'.

[2] An influential explanation of the EKC outside the field of growth theory is Andreoni & Levinson (2001), who develop a theory of the EKC that is grounded in the notion of increasing returns to scale in abatement technology.

We show how this curve, which arises on a transition path featuring a large number of heterogeneous countries, is actually composed of individual countries' Kuznets curves. In what follows, we will refer to this phenomenon as a pattern of 'overlapping Kuznets curves'.

With pollution transboundary in nature, overlapping Kuznets curves are actually a reflection of the timing and magnitude at which countries 'contribute' to preservation of the global commons. Thus, a Kuznets curve of a single country can be interpreted as its path of contributions. With differences in initial conditions, the transition path of our model is characterized by periods in which pollution is already decreasing in some countries while still increasing in others. In other words, our main contribution is to study the path and cross-country distribution of contributions to a global public good in a dynamic growth model. Our findings show that there is not likely to be a unique path of development for all countries. This could explain the difficulties in testing for the relationship between income and pollution in the context of global pollutants in cross-country studies.

Second, with few exceptions theories aimed at explaining the relationship between international trade and the environment are static in nature. Therefore, by employing a dynamic multi-country model that features trade in dirty intermediate goods we aim to be part of an ongoing endeavour to bridge the gap between the static literature on trade and the environment on the one hand and the dynamic literature on growth and the environment on the other hand.

Third and finally, a noteworthy aspect of our theory is its focus on trade in intermediate goods. As Peng et al. (2006) explain, "almost all contemporary final commodities make use of inputs bought on the world markets together with inputs available in national markets" (p2). They refer to this production structure and its associated trade flows in intermediate goods as the middle product economy. The empirical relevance of this form of trade is well documented and therefore it should be of interest to environmental economists as well. For example, Benarroch and Weder (2006) note that much of pollution is indeed generated in the production of intermediate goods. However, with a few exceptions most papers on trade and the environment focus on pollution from final goods. We explain that there are crucial differences for the design of environmental policy in this context. In a middle product economy the marginal cost of abatement is decreasing with trade intensity for *all* countries. The argument goes as follows. If trade intensity is high a large part of a country's products are consumed by foreigners. In this context stricter environmental policy that makes these products more expensive mostly affects foreigners. Therefore, in the middle product economy one would ceteris paribus expect that the control of pollution is increasing with trade intensity, a feature that is not necessarily present in other theories of trade.

We augment the multi-country endogenous growth model of Acemoglu and Ventura (2002), from here on denoted as AV, by introducing smokestack pollution. To be specific, we assume smokestack pollution is generated as an unwanted by-product in the production process of intermediate goods industries. First, as in the theory of neoclassical growth and the AK model (Romer, 1986), capital accumulation is our sole engine of growth. Second, international trade is introduced by means of a very simple Ricardian specification where each country specializes completely in a given set of intermediates. Third, we adopt the linear abatement specification of Brock and Taylor (2005). The end result is a multi-country growth model that is very tractable and offers valuable insights on global income-pollution trends.

In the next section we review the relevant literature, followed by a description of the model in the section thereafter. In the third section we explain how the marginal costs of abatement depend on international trade. We also show how the drag of pollution control on a country's growth rate falls partially on its trading partners. In the fourth section we adopt a rudimentary form of environmental policy and sketch the global dynamics of the model. The last section concludes.

6.2 Environmental Policy in Open Economies

Our analysis is related to previous studies that examine the relationship between trade, growth and the environment.[3] Here we focus on a particular issue, namely the use of environmental policy as a substitute for trade policy.

With the use of trade instruments such as tariffs and quotas increasingly constrained by trade agreements, there is a concern that governments will use environmental policy as a substitute for trade policy. By weakening environmental policy, governments can 'assist' domestic firms in competing with foreign firms. For example, Kennedy (1994) discusses this argument in a two country oligopoly model with transboundary pollution. Besides a so-called rent capture effect he also finds a pollution-shifting effect. The rent-capture or business-stealing effect states that governments can lower pollution taxes in order to increase the competitive advantage of domestic firms on international markets. This effects tends to lower Nash-equilibrium taxes. The pollution-shifting effect on the other hand tends to increase equilibrium taxes. When pollution is partially transboundary, governments will attempt to shift production and the associated level of pollution out of their jurisdiction. Copeland and Taylor (2004, pp.56-57) discuss these issues in the context of trade based on comparative advantage. They find that a dirty good importer has an incentive to set a Pigouvian tax below marginal damage whereas an exporting country has an incentive to set a tax that exceeds marginal damage.

So how does this relate to our analysis? Surprisingly, we find that international trade is a channel that allows *every* country to export part of its abatement costs. The reason is that each country is the exporter of a unique set of dirty varieties. This feature of the middle product economy gives each country an incentive to improve its terms-of-trade even though countries are small by definition. Since the market for each intermediate good is characterized by perfect competition and countries export a fraction of their intermediate goods production, governments will have an incentive to enforce monopoly power by domestic producers. The argument that a government can export pollution costs by enforcing a mark-up on goods prices is well-known in the context of partial equilibrium and builds on the fact that only domestic producer surplus and environmental damages are relevant for cost-benefit analysis of trade policies. Here we show that this argument can be extended to (i) general equilibrium and (ii) an alternative market structure where intermediate goods play an important role.

The question then is, of course, how special is this market structure? As it turns out, the workhorse

[3] Seminal contributions on growth and environment pollution are Keeler et al.(1972), Bovenberg & Smulders (1996), Stokey (1998) and many others. With respect to trade and the environment, Copeland & Taylor (1994), Grossman & Krueger (1995), Copeland & Taylor (2003) and Levinson (2009) can be seen as fairly recent milestones. For interesting reviews of the literature the reader is referred to Copeland & Taylor (2004) and Brock & Taylor (2005).

model of modern trade theory, the monopolistic competition model, can be used to derive a similar result. In a recent analysis on the differential environmental impact of international versus intranational trade, McAusland and Millimet (2010) apply a model of monopolistic competition to show how trade can lead to a decoupling of regulatory costs from regulatory benefits. McAusland and Millimet (2010) expand Krugman (1980) by assuming that environmental regulation lowers factor productivity. This implies that an increase in the stringency of environmental policy is partially passed on to (foreign) consumers in the form of higher prices. As in our model, two elements are then key to the argument that international trade is more beneficial for the environment than autarky or intranational trade. First, a market structure where each country exports an (endogenous) number of unique varieties is crucial. The implication is that countries (or firms) should have a degree of market power to pass on higher prices to foreigners. Second, the strength of the incentive to shift the costs of domestic regulation to the rest of the world is increasing in the degree of trade openness. As explained before, a high trade openness implies that a large fraction of the costs from environmental policy falls on foreigners in the form of higher prices. It can then be argued that the extent of a regulator's jurisdiction is crucial for the stringency of environmental policy since a higher degree of trade openness corresponds ceteris paribus to a smaller jurisdiction. In the model presented in the next section, this logic is presented in an extreme form because all domestically produced intermediate goods are exported to other jurisdictions, i.e. countries.

More in general one might argue that while large exporting countries, irrespective of market structure, are always able to use environmental policy to increase the terms-of-trade, small countries may or may not, depending on the market structure and demand conditions involved.[4] Now, consider the following definitions:

Definition 1 *A country is small in an economic sense if its level of income is small compared to world income.*

Definition 2 *A country is small in an environmental sense if:*

(i) pollution is (fully) transboundary and its output of emissions is small compared to world emissions.

A few remarks are in order. Whether a country is able to affect (world) prices while still being small in an economic sense depends crucially on market structure. For example, the one-sector small open economy Ramsey model has the fundamental property that firms and consumers take the world interest rate as given. In turn, this property originates from the notions that (i) there is no trade in commodities and (ii) the economy is so small, in terms of income, that it cannot affect the world interest rate. On the other hand, countries in the AV model are also small in terms of income, but they can nevertheless affect world prices by the assumption of monopoly power on world markets for intermediate goods. In McAusland and Millimet (2010) countries are large in an economic sense, but also large in an environmental sense. Large in an economic sense, because the income share and the share of

[4]Note that our specification is still different from McAusland & Millimet (2009) because we assume a fixed number of varieties in each country, while they do not. Nevertheless, AV show how their model can be reintrepeted as one where the number of varieties is endogenous, which leaves all major implications of the model unchanged, but at the cost of analytical tractability. Our setup is sufficiently rich to emphasize the 'decoupling-effect' while still allowing for analytical results.

domestically produced commodities in consumption are not negligible. Large in an environmental sense, because pollution is assumed to be local and therefore the state has an incentive to (optimally) regulate pollution. If pollution would have been (fully) transboundary in nature the regulatory decoupling effect would have been mitigated in the large-country case and even absent in the case where countries are small (in an economic sense). This is the typical problem of the commons: when pollution is transboundary and the number of nation states is very large it is rational for each individual nation state or jurisdiction to ignore the environmental consequences of its actions.

6.3 The Model

6.3.1 An Acemoglu-Ventura (2002) Dynamic Trade Model with Transboundary Pollution

We formulate a multi-country endogenous growth model with international trade in intermediate goods. To that end, we augment Acemoglu and Ventura (2002) by incorporating smokestack pollution from the production of intermediate goods. We allow for many countries. Formally, we assume a continuum of countries with mass 1. In each country there exists an infinitely lived representative agent who cares about consumption and environmental damages. There are two non-tradable final goods, one consumption (C) good and one investment (I) good. Final goods are assembled using a large number of intermediate goods. We make a distinction between non-tradable intermediate goods and tradable intermediate goods. Intermediates are produced with a linear technology using only physical capital (K) as a factor of production.

Capital is allowed to move freely between sectors, but there is no international capital mobility. Furthermore, following AV we introduce two types of asymmetries between countries. First, countries might differ in terms of their initial capital endowment. Second, countries might differ with respect to some key parameters. To be precise, a country is defined by the set (μ, ρ, ϕ), where μ is an indicator how advanced a country's technology is, ρ is the pure rate of time preference and ϕ represents total factor productivity of the investment sector. As in AV, we denote the joint time-invariant distribution of these characteristics by $G(\mu, \rho, \phi)$. Note that we will often refer to a symmetric world in terms of (μ, ρ, ϕ) in order to obtain closed form solutions.

Tradable intermediates are freely traded on world markets. Each country specializes in the production of a unique set of tradable intermediates with the measure (number) μ, with $\int_0^1 \mu dG = M$. Although μ refers to the 'number' of intermediates a country is able to produce, one might interpret it loosely as an indicator of technology as well. We assume that each country takes μ as given.

There is a degree of 'roundaboutness' in the production of final goods in the sense that production benefits from the input of all tradable intermediates that are available on world markets. This is the "international returns to scale"-argument for manufacturing, see Ethier (1982). We follow Benarroch and Weder (2006) by assuming that only one stage in the production process is polluting. Here we make the assumption that only the production of intermediate goods, traded and non-traded, generates pollution. Intermediate goods producers can abate (a part of) pollution by allocating a fraction θ of gross

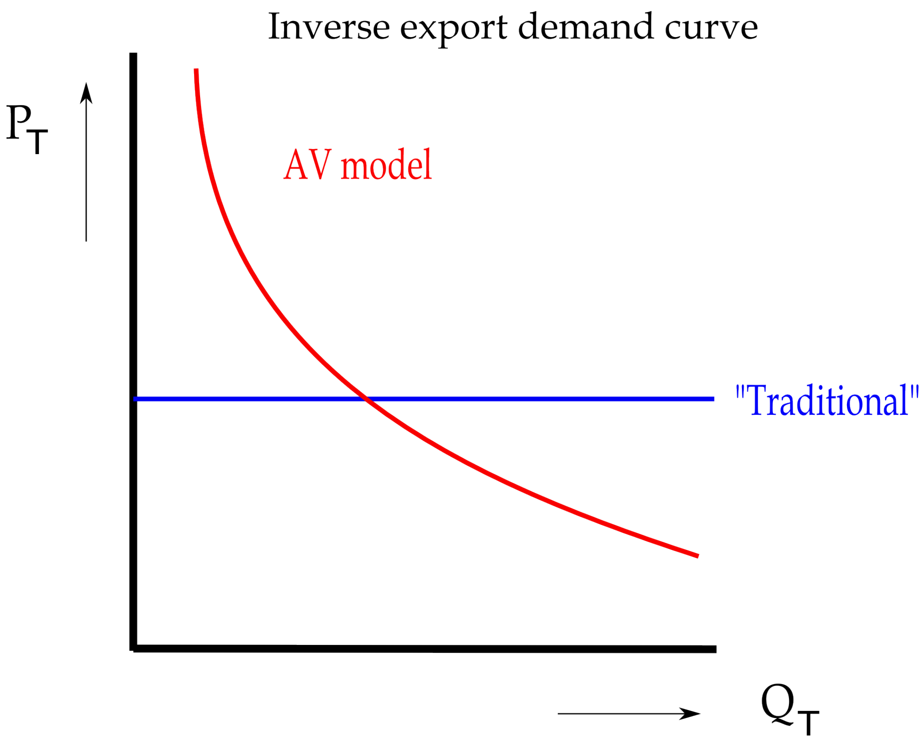

Figure 6.1: Downward sloping inverse export demand curve

output to abatement activities. Our specification of abatement follows Brock and Taylor (2003, 2005), from here one denoted as BT, which is to be explained shortly. Figure 1 depicts a crucial aspect of the model, a downward sloping inverse export demand curve for a small open economy, which will be explained further in section 3.4:

In what follows we adopt a decentralized market perspective. A representative agent maximizes intertemporal welfare by choosing the path of consumption. In order to control pollution, a benevolent government selects a production standard that firms have to meet. This production standard, or abatement intensity, corresponds directly to a certain emission intensity. We specify the details of the decisions regarding environmental policy in sections 4 and 5.

6.3.2 Welfare and Consumption

In all countries a representative consumer maximizes lifetime welfare W^i :

$$W^i = \int_0^\infty [\ln C^i(t) - \frac{1}{\gamma}(X^w(t))^\gamma]e^{-\rho t}dt \tag{6.1}$$

where $C^i(t)$ is consumption at time t in country i and X^w is the *global* pollution stock (or flow) at time t and $\gamma \geqslant 1$ is a parameter indicating the curvature of the damage function. Throughout the remaining of this chapter we avoid unnecessary notation and do not use country subscripts unless confusion would arise. The representative agent in each country faces the following budget identity:

$$y = p_C C + p_I \dot{K} + EX - IM \tag{6.2}$$

where p_C and p_I are the prices of consumption goods and investment goods and y is nominal income. Note that p_C and p_I are domestic prices by the very fact that final goods are non-tradable. We abstract from capital depreciation. For simplicity we assume that in each period exports EX equal imports IM. Thus, trade must be balanced in each period. The defining feature of our set-up is that we present a dynamic model in which countries are now both interconnected via international markets for intermediate goods and the stock (or flow) of global pollution. We elaborate more on the implications of this set-up in the following sections.

6.3.3 Production of Intermediate Goods and Final Goods

In all countries the production of one *gross* unit of an intermediate good requires one unit of capital. Because of perfect competition, the price of an unit of gross output is equal to the interest rate $r(t)$. The production of one unit of output generates $e(\theta)$ units of pollution, where θ is the fraction of gross output used for abatement and $e'(\theta) < 0$. We assume the government is able to directly control the emission intensity $e(\theta_T)$ of tradable intermediates by choosing the intensity of abatement θ_T. Similarly, the government also controls pollution in the non-tradable sector by selecting θ_N. The production function for net output of an intermediate goods reads:

$$y_N = (1 - \theta_N)K_N \quad , \quad y_T(z) = (1 - \theta_T)k(z) \tag{6.3}$$

where y_N and $y_T(z)$ refer to the output of non-tradable and tradable intermediate goods respectively. Furthermore, K_N is the level of capital employed in the non-tradable intermediate goods sector and $k(z)$ is the level of capital employed in the production of variety z, where $z \in [0, M]$. A country produces a 'number' μ of tradable intermediates, where, as indicated before, μ can be used interchangeable as an indicator of technology. Markets for intermediate goods are characterized by a large number of producers and a large number of buyers from the final goods sector and are therefore subject to perfect competition. From these assumptions it follows that the net price of an unit of an intermediate good is:

$$p_T = \frac{1}{1 - \theta_T} r \quad , \quad p_N = \frac{1}{1 - \theta_N} r \tag{6.4}$$

Several observations with respect to this abatement specification can be made. First, an increase in the intensity of abatement θ works as an increase in the *net* unit-capital requirement. In other words, changing the abatement intensity serves as a change in total factor productivity. An altogether different perspective on this specification can be made by referring to the concept of 'iceberg' costs. Iceberg costs refer to the loss of output in transport from port to destination. Here, abatement can be seen as destination-independent iceberg cost: net output is reduced to clean up pollution irrespective of the destination of the good. Having said all this, the specification of abatement assumed here is conveniently linear. We will show later on that countries have an incentive to 'overabate' in the case of tradable intermediates due to terms-of-trade externalities.

There are two final goods: one consumption good and one investment good. Final goods are produced with a roundabout constant returns to scale production process, using (i) a composite intermediate good that requires the input of (all) intermediates sold on world markets and (ii) a domestically produced intermediate good. The final good production functions read:

$$C = \chi(y_N^C)^{1-\tau}(Y_T^C)^\tau \tag{6.5}$$

$$I = \phi\chi(y_N^I)^{1-\tau}(Y_T^I)^\tau \tag{6.6}$$

$$Y_T \equiv (\int_0^M y_T(z)^{\frac{\varepsilon-1}{\varepsilon}} dz)^{\frac{\varepsilon}{\varepsilon-1}} \tag{6.7}$$

$$Y_T = Y_T^C + Y_T^I \quad , \quad y_N = y_N^C + y_N^I \tag{6.8}$$

where C and I are the output of the consumption good and the investment good, Y_T^C and Y_T^I are the inputs of the composite intermediate good in the production of the consumption good and investment good respectively, $y_T(z)$ represents the input of a tradable intermediate good in the production of the composite intermediate good, $y_N^C(z)$ and $y_N^I(z)$ are the inputs of non-tradable intermediates in the production of the consumption good and investment good, χ represents a parameter used for normalization and $\phi > 0$ is a total factor productivity parameter reflecting the relatively efficiency with which investment goods are produced compared to consumption goods. Equation (6.8) states the market clearing conditions for the composite intermediate good and the non-tradable intermediate good; at each moment in time supply must equal demand for intermediate goods from the final goods sectors.

The parameter ε is the elasticity of substitution between tradable intermediates. It also represents the price elasticity of foreign demand for the country's products and AV interpret the inverse of this elasticity as a measure of the degree of specialization. We assume $\varepsilon > 1$ since this will avoid, as we will show in section 4.3, the implausible outcome that more stringent environmental policy raises domestic income.[5] Remember, the parameter M reflects the total mass of world intermediates, with $\int_0^1 \mu dG = M$. With perfectly competitive markets prices of the consumption good and the investment good equal unit costs and are respectively given by:

$$p_C = c_C = (p_N)^{1-\tau} P^\tau \tag{6.9}$$

$$p_I = c_I = \frac{1}{\phi}(p_N)^{1-\tau} P^\tau \tag{6.10}$$

where p_N represents the price of the non-tradable intermediate good and P is a CES price index of all tradable intermediate inputs.[6] Without tariffs and trade barriers the relevant price index of intermediates

[5]Another unwarranted feature of $\varepsilon \leq 1$ is that it leads to a situation where the world growth rate on the balanced growth path is diminishing in the global mass (number) of world intermediates (see section 5.3).

[6]Here we used superscripts i to indicate explicitly that some prices are country specific, p_C^i, p_I^i and p_N^i, while the price index P is not.

P in each country is:

$$P = [\int_0^M p_T(z)^{1-\varepsilon} dz]^{\frac{1}{1-\varepsilon}} \tag{6.11}$$

Next, we turn to solve for factor market equilibrium from the balance of trade condition.

6.3.4 Market Equilibrium and Trade Balance

The capital market condition states that in each instant of time the sum of capital employed in the production of tradable intermediates, $K_T \equiv \mu k(z)$, and non-tradable intermediates (K_N) should equate the total stock of capital:

$$K = K_T + K_N \tag{6.12}$$

Under the assumption of perfect domestic capital mobility, the shares of capital used to produce tradables and non-tradables follows directly from the Cobb-Douglas functional forms of the investment and consumption good. Formally, market clearing for non-tradable intermediates requires $y_N = a_{C,N}C + a_{I,N}I$ where $a_{C,N} \equiv \frac{\partial c_C}{\partial p_N}$ and $a_{I,N} \equiv \frac{\partial c_I}{\partial p_N}$ are the unit-intermediate-good requirements for respectively the consumption good and the investment good. Using equations (6.9)-(6.10) and substituting the income identity $rK = p_C C + p_I I$ and (6.3) into this market clearing condition shows us:

$$K_N = (1-\tau)K \quad \text{and} \quad \mu k \equiv K_T = \tau K \tag{6.13}$$

where the sectoral capital stock K_T followed from (6.12). Demand for each tradable intermediate is of the constant elasticity form. With each country spending a fraction τ of income on tradable intermediates, demand for each intermediate good equals $y_T = (\frac{p_T}{P})^{-\varepsilon}\frac{1}{P}(\tau Y^w)$, where $Y^w \equiv \int rKdG$ is world income. Using the fact that $\mu k = \tau K$, multiplying by μ on both sides of the demand function, substituting $p_T y_T = rk$ into the demand function and rearranging gives:

$$\tau y = \tau\mu(\frac{p_T}{P})^{1-\varepsilon} Y^w \tag{6.14}$$

where $y = rK$ is nominal country income. Note that equation (6.14) is derived under the assumption of balanced trade: in each instant of time, total expenditures on imports of intermediate goods (τy) must equal total revenues from exports of intermediate goods ($\tau\mu(\frac{p_T}{P})^{1-\varepsilon}Y^w$). In the AV set-up with a continuum of countries each country is infinitely small. The implication is that a country essentially exports its total production of tradable intermediate goods. This is an important aspect of the model and we will explain why in the next section.

For clarification purposes, let us rewrite the investment equation (6.2) as $\dot{K} = \frac{y}{p_I} - \frac{p_C}{p_I}C$, which states that investment equals real income minus consumption. Let us denote $y_M \equiv \frac{y}{p_I} = \frac{r}{p_I}K$ as real income, i.e. nominal income deflated by the price of the investment good, to get a better picture of the dependency of real income on abatement intensity on the one hand and prices on the other hand.[7] Taking P as the numeraire and substituting prices (6.4)-(6.10) into y_M one can write:

$$y_M = \phi(1-\theta_T)p_T(p_N)^{\tau-1}K = R(\theta_N, \theta_T)K \tag{6.15}$$

where the net return on capital ($R \equiv \phi(1-\theta_T)p_T(p_N)^{\tau-1}$) is written as a function of θ_N and θ_T. A benevolent government controls pollution via the abatement intensities θ_T and θ_N. Next, we explain how these controls affect the marginal cost of abatement, $-\frac{dR}{d\theta_i}$, via three different channels. First, there is a direct total factor productivity effect via the term $(1-\theta_T)$. Second, there is an effect on the terms-of-trade via p_T. Third and finally, there is an effect via the price of non-tradables. In contrast to many other general equilibrium applications to trade and the environment, our analysis focusses on the control of abatement by acknowledging its effect on (world) prices. The argument we want to make here is similar to the optimal tariff argument in trade theory. According to this argument, large countries have an incentive to set a tariff on imports, thereby reducing the world price of imports and increasing their terms-of-trade (see for example Syropoulos, (2002)). Similarly, a large country can impose an export tariff to increase its terms-of-trade.

Whereas abatement directly lowers the TFP of capital via the first term, abatement can potentially increase real income by increasing traded goods prices. If the government directly controls the intensity of abatement via a production standard (as we have assumed), there will be a tendency to abate too much from a global welfare point of view with respect to the terms-of-trade channel. On the other hand, there will be a tendency to underabate when examining its effect on TFP. We will examine these issues in more detail in the next section. Let us now turn to the determination of global environmental quality.

6.3.5 Global Environmental Quality

Following Brock and Taylor (2005), our specification of emissions per gross unit of output equals $e(\theta_T) = (1-b\theta_T)$ for tradable intermediates and $e(\theta_N) = (1-b\theta_N)$ for non-tradable intermediates, with $b > 1$. When abatement intensity is maximized, $\theta_N = \theta_T = 1/b < 1$, society has effectively adopted zero-emissions technologies in all intermediate sectors, $e_T(1/b) = e_N(1/b) = 0$. The key assumption underlying this specification is that diminishing returns at the firm level that lead to rising marginal abatement costs, are undone by technological process linked to aggregate abatement intensity leaving the social marginal cost of abatement constant.[8]

Now, total pollution D^i in country i is the sum of pollution over all intermediates, $D^i = (1 - b\theta_T^i)K_T^i + (1-b\theta_N^i)K_N^i$. Using the identities for sectoral capital shares, equation (6.13), we retrieve

[7] Normally one would define real income as nominal income deflated by a consumer price index. However, since the price of the consumption good and investment good are equal up to a constant, our definition is very close to real income and more appropriate here since it appears in the rewritten investment equation.

[8] For a more detailed specification the reader is referred to Brock & Taylor (2003).

world pollution as the sum of emissions emitted from all countries:

$$\begin{aligned} D^w &= \sum_i D^i = \sum_i [(1-b\theta_T^i)\tau + (1-b\theta_N^i)(1-\tau)]K^i \\ &= \sum_i e(\theta_N^i, \theta_T^i)K^i \end{aligned} \tag{6.16}$$

where $e(\theta_N^i, \theta_T^i) \equiv [(1-b\theta_T^i)\tau + (1-b\theta_N^i)(1-\tau)]$ reflects the net emission intensity of country i. Each country's net emissions intensity is a Cobb-Douglas weighted average of the net emission intensities in the tradable and non-tradable intermediate good sectors. Total pollution emitted is thus directly determined by the average intensity of abatement in each country and the capital stock in each country. Pollution that is emitted into the atmosphere, greenhouse gasses for example, builds up a stock of pollution according to the well-known 'sink-specification' of environmental quality:

$$\dot{X}^w(t) = D^w(t) - \eta X^w(t) \tag{6.17}$$

where $X^w(t)$ is the global stock of environmental pollution at time t, and η represents the constant capacity to regenerate. If η is very large then the sink function is said to have a high capacity to absorb human waste or pollution. In the absence of pollution, the environment regenerates exponentially at rate η.

Next, and before setting-up the general solution to our model, we discuss the concept and relevancy of terms-of-trade spillovers in determining the optimal abatement intensity in open economies. Our primary interest lies with the examination of the non-cooperative case where in every country a planner selects the standards of production in a yet to be defined manner.

6.4 Exogenous Environmental Policy

6.4.1 Regulatory Decoupling

As an aid to interpreting our results, we follow McAusland and Millimet (2010) by defining regulatory decoupling. In the context of our model, more stringent domestic environmental regulation has only a small effect on final good producers since prices of intermediate goods produced in other countries are not affected by domestic regulation. In addition, more stringent environmental regulation will be passed through to both foreign and domestic consumers of domestic intermediate goods in the form of higher prices. If the extent to which these costs are passed through to foreigners is large, strict environmental policy becomes more attractive to domestic policymakers. An increase in trade intensity will increase the magnitude of this effect. Hence, we define regulatory decoupling as an increase in the degree to which the costs and benefits of domestic environmental policy are borne by consumers and producers in different countries, resulting from an increase in trade intensity. Next, let us commence with the formal analysis.

6.4.2 Terms-of-Trade and Regulatory Decoupling

To prepare for the dynamic analysis yet to come, we solve for the effects of marginal changes in abatement intensity on the interest rate and prices of intermediate goods. We begin by considering unilateral changes in production standards. There are two cases to consider: (i) a country with zero mass and (ii) a country (or block of countries) with positive mass. In the latter case, interest rates in other countries are affected, whereas in the first case they are not. We will show that in each case the effect on the interest rate can be split in two terms. The first term resembles a positive optimal tariff argument in the tradition of Johnson (1953). The second term represents a negative productivity effect.

For a zero-mass country, differentiating (6.4), (6.14) and $y = rK$ with respect to r, θ_T, p_N and p_T, while keeping K, Y^w and θ_N constant, and rearranging shows:

$$\frac{dr}{d\theta_T} = -\frac{\varepsilon-1}{\varepsilon}p_T = \left(-1+\frac{1}{\varepsilon}\right)p_T < 0 \ , \ \frac{dp_T}{d\theta_T} = \frac{1}{1-\theta_T}\frac{p_T}{\varepsilon} > 0 \tag{6.18}$$

$$\frac{dp_N}{d\theta_T} = -\frac{\varepsilon-1}{\varepsilon}\frac{p_T}{1-\theta_N} < 0$$

One way to interpret these results is as follows. First, observe that the interest rate can be written as $r = (1-\theta_T)p_T$. Second, inspection of this identity shows that a marginal change in θ_T lowers r via a negative productivity (TFP) effect, $\frac{\partial r}{\partial \theta_T} = -p_T$, and increases r via a positive terms-of-trade effect, $\frac{dr}{dp_T}\frac{dp_T}{\theta_T} = \frac{p_T}{\varepsilon}$, but the overall effect is unambiguously negative. With symmetric countries rearrange (6.11) to obtain $r = (1-\theta_T)M^{\frac{1}{\varepsilon-1}}$ and subsequently $\frac{dr}{d\theta_T} = -\frac{\varepsilon-1}{\varepsilon}M^{\frac{1}{\varepsilon-1}}$ and $\frac{dp_T}{d\theta_T} = \frac{1}{\varepsilon}\frac{1}{1-\theta_T}M^{\frac{1}{\varepsilon-1}}$. The price of the non-tradable good changes as well, since the domestic interest rate is affected. To consider the effects of a marginal change in θ_N, differentiate (6.4) and (6.14) with respect to r, θ_N, p_N and p_T, while keeping K, Y^w and θ_T constant to obtain the following derivatives:

$$\frac{dr}{d\theta_N} = 0 \, , \frac{dp_T}{d\theta_N} = 0, \ \ \frac{dp_N}{d\theta_N} = \frac{p_N}{1-\theta} > 0$$

For a small country, a marginal change in θ_N raises the price of non-tradable goods directly by a negative productivity effect. This price hike falls on domestic producers of final goods only and therefore abatement in the tradable sector is strictly preferred over abatement in the non-tradable sector.

Next, we perform comparative statics for the non-cooperative large country case. Suppose there are N symmetric countries with positive mass. Consider a representative country, denoted by A, and refer to all $N-1$ other countries by subscript or superscript B. Total differentiation of the price index (6.11) and the balanced trade condition (6.14) with respect to r_A, r_B, θ_T^A, p_T^A, p_T^B, while keeping K_A, K_B, θ_N^A, θ_N^B and θ_T^B constant, and then rearrange these equations to get:

$$\frac{dr_A}{d\theta_T^A} = -p_T + \frac{p_T}{\varepsilon} - \frac{p_T}{\varepsilon N} = -\frac{1+N(\varepsilon-1)}{N\varepsilon}p_T < 0 \quad , \quad \frac{dr_B}{d\theta_T^A} = -\frac{1}{N\varepsilon}p_T < 0 \tag{6.19}$$

where we imposed symmetry, $\theta_T^A = \theta_T^B$ etc., to evaluate these derivatives in the symmetric equilibrium.

To determine the effect on the terms-of-trade p_T, we derive the total derivatives with respect to θ :

$$\frac{dp_T^A}{d\theta_T^A} = \frac{N-1}{N\varepsilon}\frac{p_T}{1-\theta_T} = \frac{p_T}{1-\theta_T}[1-\frac{1+N(\varepsilon-1)}{N\varepsilon}] > 0 \quad , \quad \frac{dp_T^B}{d\theta_T^A} = -\frac{1}{N\varepsilon}\frac{p_T}{1-\theta_T} < 0 \tag{6.20}$$

Again, note that from $(1-\theta_T)p_T$ we find $\frac{\partial r}{\partial \theta_T} = -p_T$ and $\frac{dr}{dp_T}\frac{dp_T}{\theta_T} = \frac{p_T}{\varepsilon} - \frac{p_T}{\varepsilon N}$, where the last term is new compared to (6.18) and represents a weakening of the terms-of-trade effect.

A comparison of the results under (6.18) and (6.19)-(6.20) allow us to explain the concept of regulatory decoupling. In contrast to a small country, a large country consumes a positive fraction of its own intermediates. Next to the negative TFP effect that affects the interest rate ($-p_T$), which is relevant for small and large countries alike, regulators in a large country will have to internalize higher prices resulting from domestic environmental policy as well since they fall partially on domestic final good producers. Formally, compare the terms-of-trade effects between large countries and small countries, that is, compare $\frac{p_T}{\varepsilon} - \frac{p_T}{\varepsilon N}$ from (6.19) to $\frac{p_T}{\varepsilon}$ from (6.19) and note that $\frac{p_T}{\varepsilon} - \frac{p_T}{\varepsilon N} < \frac{p_T}{\varepsilon}$ for all $N \in [0, \infty)$. At the same time, the environmental benefits from a higher standard are not affected by country size. Therefore, the extent of regulatory decoupling can be said to decrease if country size increases. Since we have assumed symmetric countries another way to put this is to say that regulatory decoupling increases if the number of countries increases.

Now let us define the marginal cost of meeting the standard in the tradable sector in country i as the opportunity cost in util terms of meeting the standard, $MAC_T^i \equiv -\frac{\partial}{\partial\theta_T}(\ln\frac{y_i}{p_C^i}) = -\frac{\partial}{\partial\theta_T^i}(\ln(r_i)^\tau(1-\theta_N^i)^{1-\tau}K^i) = -\tau\frac{1}{r_i}\frac{dr_i}{d\theta_T^i}$, where we have substituted from (6.9) and $y_i = r_iK_i$. We can then show that regulatory decoupling is synonymous with a MAC_T^i that is decreasing with trade intensity. Trade intensity T can be defined as the sum of imports and exports over GDP, that is, $T \equiv \frac{IM+EX}{GDP} = \frac{2\mu p_T y_T}{y} = \frac{2\tau\frac{N-1}{N}y}{y} = 2\tau\frac{N-1}{N}$, where we have assumed symmetry. Thus, a small country ($N \longrightarrow \infty$) has a trade intensity that is equal to or smaller than 2, which occurs if final goods are produced with tradable intermediates only, $\tau = 1$. Using this equation for trade intensity, assuming symmetry, and substituting from (6.19), we can rewrite MAC_T^i as a function of trade intensity:

$$MAC_T = \tau\frac{1}{1-\theta_T}[\frac{\varepsilon-1}{\varepsilon} + \frac{1}{\varepsilon}\frac{T_{\max}-T}{T_{\max}}]$$

where $T_{\max} \equiv 2\tau$ and $T \in [0, 2\tau]$.[1] This equation shows that the marginal cost of meeting the standard is decreasing in the degree of specialization $\frac{1}{\varepsilon}$ (ignoring indirect effects via θ_T), and increasing in the relative distance from maximum trade intensity $\frac{T_{\max}-T}{T_{\max}}$. Consider the following figure:

We are now able to state the following proposition:

Proposition 1 *In the middle product economy with trade in intermediate goods each country can use a production standard in the tradable sector as a means to increase its terms-of-trade. The effect of environmental policy on the terms-of-trade is decreasing (increasing) with country size (with trade intensity).*

[1]The maximum trade intensity $T_{\max}$ follows directly from $\lim_{N\longrightarrow\infty} T = \lim_{N\longrightarrow\infty} 2\tau\frac{N-1}{N} = 2\tau$.

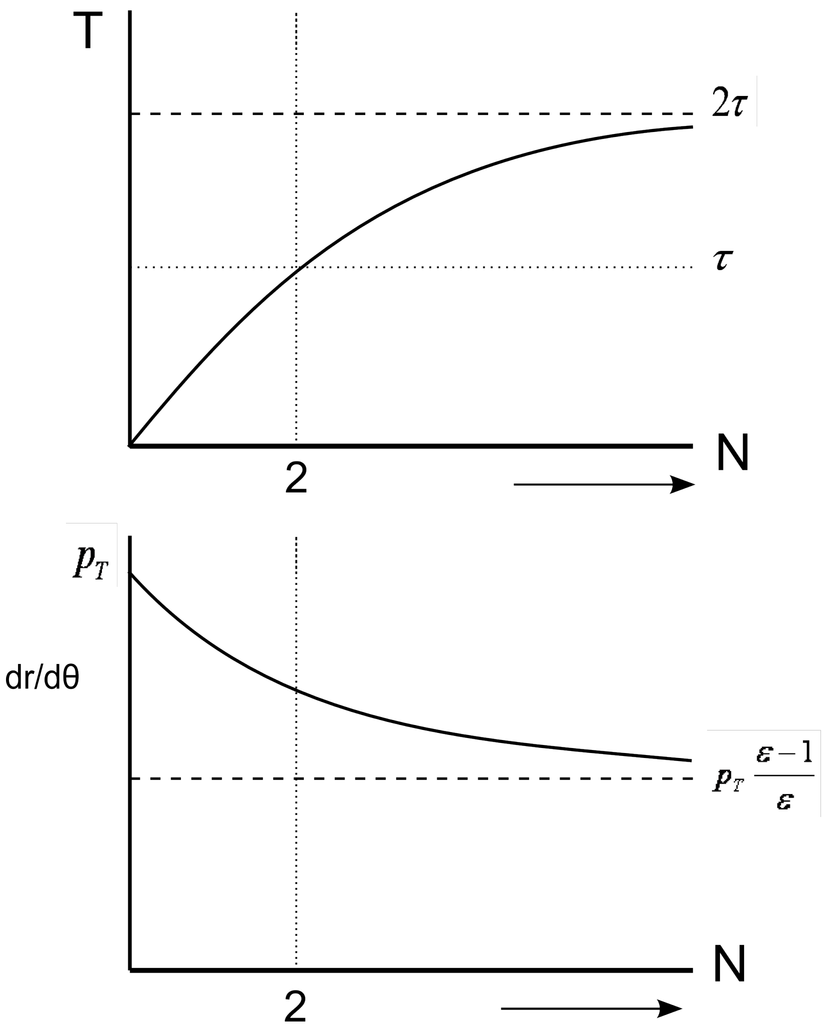

Figure 6.2: Trade intensity and the marginal cost of meeting the domestic standard.

Proposition 1 explains why for any given level of environmental control a large country is worse off than a small country. This is because for a large country it is more expensive to export its environmental policy in the form of higher prices than a small country unless, of course, it would be willing to engage in price discrimination between domestic consumers and foreign consumers of domestically produced intermediates.

The non-cooperative solution entails a typical prisoner's dilemma: in the absence of cooperation each country decides it is in it best interest to raise abatement intensity, thereby overabating compared to what is optimal from a global point of view. There are thus two opposite externalities to consider in the non-cooperative solution: a negative terms of trade spillover and a negative transboundary spillover. Whereas the latter tends to result in too much pollution the first tends to result in too little pollution, because countries can export a part of their marginal cost of abatement.

6.5 Behavior by Maximizing Agents: Consumers, Producers and Governments

In previous sections we described the competitive markets for intermediate goods and final goods. In what follows we will describe the behavior by national governments first and turn to the intertemporal optimization problem faced by consumers in the section thereafter. In our set-up with a continuum of countries and transboundary pollution, each country's impact on world pollution is negligible. In other words, free-riding is maximized and each country will abstain from any contribution to the global commons. Therefore, we assume that the world is partitioned in a discrete number of groups. We assume that these groups have solved the problems of the commons partially and require each of its members to maximize group welfare by settings its marginal cost of abatement equal to the marginal benefits of abatement for all group members. This will be explained in more detail shortly hereafter.

Now, let us summarize the maximizing behavior of the various agents. First, in each country (i) producers maximize profits in competitive markets, (ii) consumers maximize welfare by choosing the intertemporal path of consumption and (iii) governments implement the group rule for environmental policy. Second, producers and governments effectively solve static problems whereas consumers are fully forward looking. Consumers ignore the implications of their behavior for government policy and vice versa. Whereas the first part of this assumption is obvious, since consumers are small by definition, the latter is not. We view this assumption as a necessary requirement in order to obtain analytically tractable results. In addition, we will show that it only requires one to assume that governments do not want to use environmental policy as an instrument to influence savings behavior.

6.5.1 A Simple Specification of Endogenous Environmental Policy

In this section countries are assumed to be small, both in an economic sense as in an environmental sense.[9] Pollution is fully transboundary and assumed to dissipate completely after each period. Thus,

[9] Of course, in Acemoglu & Ventura (2002) countries are small in an economic sense by definition due to the assumption of a continuum of countries with mass one. Thus, countries are atomistic.

in this section we assume damages arise from flow pollution only, $X^w = D^w$. The world economy is exogenously divided into N groups (or federations), each consisting of a large number of small countries, such that $\sum_{j=1}^{N} n_j = 1$, where $n_j > 0$ is the mass of countries in group j. Welfare for country i in each moment of time is given by $V^i \equiv \ln(C_i) - \frac{1}{\gamma}(D^w)^\gamma = \ln(1-s_i) + \ln y_i - \ln p_C^i - \frac{1}{\gamma}(D^w)^\gamma$ where s_i is the endogenous savings rate of country i and where we substituted for $C_i = (1-s_i)y_i/p_C^i$. Welfare of group j is given by $V^j \equiv \int_{i\in n_j} V^i di$.

We define the instaneous marginal cost of meeting the domestic standard in country i (in group j) for the tradable goods sector, $MAC_T^i \equiv \frac{\partial}{\partial\theta_T^i}(\ln \frac{y_i}{p_C^i}) = \frac{\partial}{\partial\theta_T^i}(\ln(r_i)^\tau(1-\theta_N^i)^{1-\tau}K^i)$, where we have substituted from (6.9) and $y_i = r_i K_i$. In addition, let us define the instaneous marginal benefits for group j from meeting the domestic standard in the tradable sector in country i, $MB_T^{i,j} \equiv \frac{\partial}{\partial\theta_T^i}(\int_{j\in n_j}\frac{1}{\gamma}(D^w)^\gamma dj)$. Analogous to these definitions, we can define the marginal costs and marginal benefits from meeting the domestic standard in the non-tradable sectors as $MAC_N^i \equiv \frac{\partial}{\partial\theta_N^i}(\ln(r_i)^\tau(1-\theta_N^i)^{1-\tau}K^i)$ and $MB_N^{i,j} \equiv \frac{\partial}{\partial\theta_N^i}(\int_{j\in n_j}\frac{1}{\gamma}(D^w)^\gamma dj)$ respectively. Straigtforward differentiation leads to $MAC_T^i = -\frac{\tau}{r_i}\frac{dr_i}{d\theta_T^i}$ and $MAC_N^i = \frac{1-\tau}{1-\theta_N}$.

Now the optimal policy rule in each group for both the tradable and non-tradable sector is as follows. We assume that each country in group j equates the marginal cost of meeting the domestic standard in the tradable (non-tradable) sector, MAC_T^i (MAC_N^i), to the marginal benefits of meeting that standard for all group members, $MB_T^{i,j}$ ($MB_N^{i,j}$). Implicitly, this implies that policy makers ignore issues related to dynamic efficiency and pollution control. Hence, as in Copeland and Taylor (1997) we adopt a myopic optimization rule as an approximation to complex government behavior, i.e., the complexities of environmental policy making in an international setting.[10]

Now totally differentiating group welfare V^j with respect to θ_T^i and θ_N^i gives us $\frac{\partial V^j}{\partial\theta_T^i} = MAC_T^i - MB_T^{i,j}$ and $\frac{\partial V^j}{\partial\theta_N^i} = MAC_N^i - MB_N^{i,j}$ respectively, where it was implicitly assumed that countries are not concerned with internalizing the costs of environmental policy for their group members.[2] Next, setting $\frac{\partial V^j}{\partial\theta_T^i} = 0$ and $\frac{\partial V^j}{\partial\theta_N^i} = 0$ gives us the optimal policy rules for country i:

$$MAC_T^i = MB_T^{i,j}; \quad -\frac{\tau}{r_i}\frac{dr_i}{d\theta_T^i} = b\tau(\int_{j\in n_j}(D^w)^{\gamma-1}dj)K_i \tag{6.21}$$

$$MAC_N^i = MB_N^{i,j}; \quad \frac{1-\tau}{1-\theta_N} = b(1-\tau)(\int_{j\in n_j}(D^w)^{\gamma-1}dj)K_i \tag{6.22}$$

From the previous section we can insert (6.18) to find $MAC_T^i = \tau\frac{\varepsilon-1}{\varepsilon}\frac{1}{1-\theta_T}$. A few observations with respect to these policy rules can now be made. Although the domestic return on capital is determined both by world variables and by the intensity of abatement it has no direct influence on the marginal cost of meeting the domestic standard, which is a direct consequence of our simplifying assumption of

[10] Copeland & Taylor (1997) explain how such an approach reflects the fact that governments do not properly account for intergenerational considerations, among other things. In another important contribution to trade and the environment, Copeland & Taylor (2009) assume a risk-neutral agent which also results in a static resource management rule in what is otherwise a fully dynamic model.

[2] Doing so introduces an additional complication which, although interesting, makes the model analytically intractable. Thus, countries internalize the benefits of their mitigation efforts for group members, not the costs.

logarithmic utility. The marginal benefits from meeting the domestic standard on the other hand depend on the level of economic development, as characterized by the domestic capital stock, and the level of world pollution. Comparing (6.22) and (6.21) also learns us that in general the time path for abatement intensity will differ across sectors. In fact, a quick evaluation of these policy rules shows us that for $\theta_T^i = \theta_N^i = \theta \geq 0$ the marginal costs are ranked as:

$$MAC_T^i(\theta_T^i) < MAC_N^i(\theta_N^i) \Leftrightarrow \frac{\tau}{1-\tau} < \frac{\varepsilon}{\varepsilon - 1}$$

6.5.2 Equilibrium with Overlapping Kuznets Curves

Following the policy rules that were set out in the previous section, let us assume a setting where governments do not differentiate or discriminate between the tradable and non-tradable good sector. Subsequently $\theta_N = \theta_T = \theta$, where θ is determined endogenously by each country. As explained in the previous section, countries equate the marginal cost of meeting the domestic standard to the marginal benefits of doing so for block j. Since there is only one instrument by assumption, each country adheres to the following policy rule:

$$\frac{1}{1-\theta}\xi = b\left(\int_{j \in n_j} (D^w)^{\gamma-1} dj\right) K_i \tag{6.23}$$

where $\xi \equiv 1 - \frac{\tau}{\varepsilon} > 0$. Note that equation (6.23) can be obtained directly from summing over equations (6.21) and (6.22). Since ξ is decreasing in τ and increasing in ε, the marginal cost of meeting the domestic standard is decreasing in the level of openness to trade and increasing in the degree to which countries are specialized. A high degree of trade openness implies that the world economy is more interconnected, thereby making pollution control cheaper for individual countries due to a high degree of regulatory decoupling. Similarly, a low value of ε implies a high degree to which countries are specialized (substitution between intermediates is difficult), which also makes pollution control cheaper.

A representative agent maximizes (6.1) subject to (6.2), (6.15), $IM = EX$ and an initial condition for the capital stock, $K^i(0) = K_0^i$. This provides us with the following set of first-order conditions:

$$1/C = \lambda \frac{p_C}{p_I} \tag{6.24}$$

$$\dot{\lambda} - \rho\lambda = -\lambda R \tag{6.25}$$

$$\lim_{t \longrightarrow \infty} \frac{p_C}{p_I} \frac{C}{K} e^{-\rho t} = 0 \tag{6.26}$$

where the dynamics of the co-state variable, equation (6.25), follow directly from applying definition 2 ($\frac{\partial D^w}{\partial K^i} = 0$). Remember that we defined the net return on capital $R \equiv \phi(1-\theta_T)p_T(p_N)^{\tau-1}$ below equation (6.15). Differentiating (6.24) and using (6.25) gives us the familiar Euler equation, $\dot{C}/C = -\dot{\lambda}/\lambda = R - \rho$. Integration of both the Euler equation and the investment equation (6.2) and using

(6.26) shows us that $\frac{p_C}{p_I}\frac{C}{K} = \rho$.[11] For simplicity, and since it does not qualitatively affects our results, we impose a unique environmental policy, $\theta_N = \theta_T = \theta$ which subsequently implies that $p_N = p_T = p = \frac{r}{1-\theta}$.[12] The model is now fully characterized by the following set of equations (see the appendix):

$$\dot{K} = \phi[(1-\theta)p^{\tau}]K - \rho K \tag{6.27}$$

$$\dot{\lambda} - \rho\lambda = -\lambda\phi[(1-\theta)p^{\tau}] \tag{6.28}$$

$$rK = \mu p^{1-\varepsilon} Y \tag{6.29}$$

$$\frac{1}{1-\theta}\xi = bn_j(D^w)^{\gamma-1}K \tag{6.30}$$

$$D^w = \int_0^1 [1 - b\theta_i]K_i di \tag{6.31}$$

$$p = \frac{r}{1-\theta} \tag{6.32}$$

Next, let us define the growth rates of output, consumption, capital, the fraction of output that is used for abatement and the co-state variable for a given country by g_Y, g_C, g_K, g_θ and g_λ respectively. From the first-order conditions it follows immediately that $g_Y = g_C = g_K = -g_\lambda = \phi(1-\theta_T)p_T(p_N)^{\tau-1} - \rho$. The growth rate of world pollution g_{DW} is given by:

$$g_{D^W} = \int_0^1 g_K di - \int_0^1 \frac{b\theta}{1-b\theta} g_\theta dG$$

Next, we characterize the equilibrium of the world economy. In this section and the next we will first describe and then prove existence and uniqueness of a stable steady state in which all countries grow at the same rate. First, to describe the steady state define the world growth rate by $g = \dot{Y}/Y$. Second, setting an identical growth rate for all countries, $\dot{K}/K = \dot{y}/y = g$, rewriting (6.27) and denoting steady state variables with an asterisk (*) gives us the steady-state cross section of interest rates, $r^* = (\frac{b}{b-1})^{\frac{1-\tau}{\tau}}(\frac{\rho+g^*}{\phi})^{1/\tau}$, where we have substituted $1-\theta = 1 - 1/b$. Substitution of the steady state interest rate into the world price index (6.11) then provides us with a set of two equations that implicitly describes the cross-section of interest rates and the common world growth rate:

$$r^* = (\frac{b}{b-1})^{\frac{1-\tau}{\tau}}(\frac{g^*+\rho}{\phi})^{1/\tau} \tag{6.33}$$

$$1 = \int_0^1 \mu(\frac{b-1}{b})^{\frac{\varepsilon-1}{\tau}}(\frac{\phi}{g^*+\rho})^{\frac{\varepsilon-1}{\tau}} dG \tag{6.34}$$

Existence of a balanced growth path with sustainable development is proven in the following proposition. Sustainable development requires continuous output growth combined with a zero growth rate of pollution. Furthermore, we define absolute convergence as cross-country equalization of levels of real

[11] See the appendix for a full derivation of this result.

[12] We will come back to the implications of $\theta_N \neq \theta_T$ in section 5.3.

income and relative convergence as cross-country equalization of growth rates of output. We can then state the following proposition:

Proposition 2 *(i) There exists a balanced growth path with sustainable development for the world economy where $g_Y = g_K = g_C = g^* > 0$ and $g_{D^w} = 0$, where g^* is the steady state common rate of growth for all countries. The distribution of interest rates and g^* are summarized by (6.33)-(6.34). With full symmetry, $r^* = \frac{b-1}{b} M^{\frac{1}{\varepsilon-1}}$ and $g^* = \phi(\frac{b-1}{b}) M^{\frac{\tau}{\varepsilon-1}} - \rho$. (ii) There is relative convergence but not absolute convergence between countries. (iii) For the symmetric country case the following comparative statics results can be obtained: sustainable development is more difficult, that is, g^* is smaller, when (a) the total mass of,world intermediates M is smaller, (b) productivity of investment ϕ is low, (c) the time discount rate ρ is higher, (d) the degree of specialization increases (high ε), (e) the level of trade openness τ is low and (f) the costs of abatement $1/b$ are large.*

Proof (i) Equation (6.34) implicitly defines the unique world rate of growth g^*, which is positive provided the average investment technology ϕ is large enough, the average intermediate goods technology μ is large enough and the average rate of time preference ρ is small enough. Provided this is the case, we have $g_Y = g_K = g_C = g^* > 0$. In a steady state we must have $g_\theta = 0$ which leads to sustainable development ($g_{DW} = 0$) if and only if $\theta = 1/b$. Sustainable development, $g^* > 0$ and $g_{DW} = 0$, is then feasible if the average abatement technology is sufficiently productive such that $g^* > 0$ from (6.34). With countries that are fully symmetric, applying symmetry to equations (6.33)-(6.34) and rearranging gives us $r^* = \frac{b-1}{b} M^{\frac{1}{\varepsilon-1}}$ and $g^* = \phi(\frac{b-1}{b}) M^{\frac{\tau}{\varepsilon-1}} - \rho$. Full symmetry also provides for a clear picture with respect to the requirements on ϕ, ρ and $M = \int \mu dG$ in order to find a positive growth rate. (ii) Relative convergence follows immediately from the definition of g^*. Absolute convergence does not take place since levels of capital are not necessarily equalized (iii) Follows directly from differentiation of g^*, equation (6.34), with respect to $\{M, \phi, \rho, \varepsilon, \tau, b\}$. This completes the proof.

While comparative statics are particularly easy to derive for the case of symmetric countries, all our results go through with asymmetries as well. All that is needed is an average increase or decrease in a given parameter for a group of countries with finite mass. Although this proposition indicates the possibility of a balanced growth path with sustainable development we still have to proof global stability, to which we turn next.

6.5.3 Evolution of World Pollution

Now that we have characterized the model in equations (6.27)-(6.32), under the assumption of a relatively simple set of policy rules, we are ready to describe the evolution of world pollution in our model. During the transition towards the balanced growth path, the evolution of world pollution can be described in four stages. When countries are relatively poor they will decide not to abate at all ($\theta = 0$). This is the first stage. In terms of equation (6.30), the marginal cost of meeting the domestic standard are larger than the marginal benefits from meeting that standard ($\frac{1}{1-\theta_i}\xi = \xi > bn_j(D^w)^{\gamma-1}K_i$). In the second stage, countries that are relatively rich start abating ($0 < \theta < 1/b$). This implies that for some countries equation (6.30) will hold with strict equality. In the third stage, relatively rich countries will reach a path of sustainable development. This means that for these countries (6.30) will hold with an strict inequality again. Depending on the income differences between countries, there might still be some countries that have not reached the stage at which they start to abate. In the final and last stage, all countries will have implemented a zero-emissions technology ($\theta = 1/b$).

Next, we can determine global stability of the balanced growth path with sustainable development. To this end let us define the net marginal cost of meeting the domestic standard, using the policy rule (6.30), as $S_i \equiv \frac{1}{1-\theta_i}\xi - bn_j(D^w)^{\gamma-1}K_i \gtrless 0$. Then, depending on a country's level of development (as characterized by K_i) and the state of the global environment (given by D^w) a country:

(i) does not abate pollution at all ($S_i > 0$)

(ii) abates some of its pollution ($S_i = 0$)

(iii) implements the Kindergarten Rule, $\theta = 1/b$ (see Brock and Taylor, 2005), and does not pollute at all ($S_i < 0$).

In general we will refer to countries under (i) ((iii)) as those that follow an unsustainable (sustainable) path of development. Let us denote the mass of countries that follow an unsustainable path of development at time t by $u(t)$. Similarly, denote the mass of countries that follow an interior solution at time t ($S_i = 0$) and a sustainable solution ($S_i < 0$) at time t respectively as $m(t)$ and $v(t)$. Then, at any point in time $u + m + v = 1$. From (6.30) we find that the ranking of countries on the interval $[0, 1]$ also coincides with the natural ranking of poor to rich if and only if $n_j = n = 1/N$. If this does not hold, then a relatively poor country that resides within a large group may start abating sooner than a relatively rich country that resides within a small block. Formally, the distribution of countries at any instance in time can be described by 7 possible configurations (see the appendix). A necessary condition for global stability is related to the transition through these possible configurations:

$$\lim_{t \longrightarrow \infty} v(t) = 1 \tag{6.35}$$

stated otherwise, $\lim_{t\longrightarrow\infty} u(t)+m(t) = 0$. We first proof that the growth-rate is declining in all regimes so the differential equation for each country in K is stable:

Lemma 1 *The growth rate g is positive but declining during all stages of development.*

Proof See the appendix.

Once all countries have implemented the Kindergarten Rule ($v = 1$) lemma 1 tells us that all countries will converge to the common growth rate g^*. It remains to be proven that, starting from any initial condition, all countries enter a regime with $S_i < 0$ in finite time. In turns out that this is a relatively easy endeavor.

Proposition 3 *Starting from an initial distribution with $u = 1$ the distribution of countries will eventually satisfy $v = 1$. Once $v = 1$ we will remain in $v = 1$.*

Proof The initial distribution of capital stocks across countries is defined by $K^i(0) = K_0^i > 0$ for all i and $\int K_0^i di \equiv K_0^w$. Then this distribution will satisfy $S_i > 0$ for all i if and only if $K_0^i(K_0^w)^{\gamma-1} < (\frac{1}{bn_j})$

for all i. For example, with full symmetry this holds if $K_0 < (\frac{1}{bn})^{1/\gamma}$. By the previous lemma we enter a regime with $m > 0$ and $u + m = 1$ in finite time. As long as $v < 1$ we must have $D^w > 0$. This implies that for all countries the right-hand side of (6.30) will eventually grow without bounds, even though pollution D^w decreases eventually (but remains positive). From this argument it follows that all countries will eventually end in m and subsequently in v. Suppose that some countries do not. Then pollution must be positive and again the right-hand side of (6.30) will grow without bounds such that all countries must enter $S_i < 0$ in finite time. Regression from v into u or m is not possible since that would immediately violate (6.30). This completes the proof.

Global stability of the long-run world income distribution is a necessary outcome of our model, pretty similar to the original AV model without pollution. Now define $\underline{K}^i \equiv \frac{1}{bn_j}\xi(D^w)^{1-\gamma}$ as the level of capital at which country i starts abating, i.e. equation (6.30) holds while $\theta = 0$, and $\bar{K}^i \equiv \frac{1}{n_j}\frac{1}{b-1}\xi(D^w)^{1-\gamma}$ as the level at which a country reaches a level of sustainable development ($\theta = 1/b$). Now consider the following proposition.

Proposition 4 *Consider the transitional dynamics of the AV model with transboundary pollution. (i) In each country, the level of pollution D^i follows an environmental Kuznets curve (EKC) if and only if $K_i(0) < \underline{K}^i$. Global pollution D^w also follows an EKC pattern if $K_i(0) < \underline{K}^i$ for all i. (ii) Each country follows an identical process of economic development regarding the onset and end of the EKC pattern, $\underline{K}^i = \underline{K} = \frac{1}{bn_j}\xi$ and $\overline{K}^i = \overline{K} = \frac{1}{n_j}\frac{1}{b-1}\xi$, if and only if the damage function is linear ($\gamma = 1$), countries are part of the same group or a group of similar size and countries have identical abatement technologies.*

Proof (i) By definition a country will start abating at $\underline{K}^i$. Therefore, a country with $K_i(0) < \underline{K}^i$ will first witness an increase in emissions due to a phase of growth without abatement. By the previous proposition it will reach a regime with maximum abatement in finite time at $\bar{K}^i$. Once abatement has progressed sufficiently emissions will start to decline. For countries with $K_i(0) \in [\underline{K}^i, \bar{K}^i]$ pollution might increase at first, and decrease thereafter. Countries with $K_i(0) > \bar{K}$ immediately enter a phase with zero pollution. Global emissions also describe an environmental Kuznets curve pattern, depending on whether 'sufficient' countries start with $K_i(0) < \underline{K}$. Once all countries reach $\bar{K}$ world pollution ceases, $D^w = 0$. (ii) Substitution of $\gamma = 1$ and $\theta = 0$ into (6.30) immediately shows $\underline{K} = \frac{1}{bn_j}\xi$. Substitution of $\theta = 1/b$ gives us $\bar{K} = \frac{1}{n_j}\frac{1}{b-1}\xi > \underline{K}$. Obviously, $\underline{K}$ and $\bar{K}$ are identical across a given set of countries assuming n_j and b are identical as well. For $\gamma > 1$ we have $\underline{K}^i = \frac{1}{bn_j}\xi(D^w)^{1-\gamma}$ and $\bar{K}^i = \frac{1}{n_j}\frac{1}{b-1}\xi(D^w)^{1-\gamma}$, which are dependent on D^w. Since D^w changes continuously, it follows directly that $\underline{K}$ and $\bar{K}$ are no longer identical across countries that differ in their initial stock of capital. This completes the proof.

The previous proposition indicates that our model provides for a relatively simple representation of the relationship between economic development and the timing and onset of pollution control in each country. The following figure is indicative of part (i) of proposition 4 in sketching the qualitatively different types of relationships between the "level of development" and the level of the production standard:

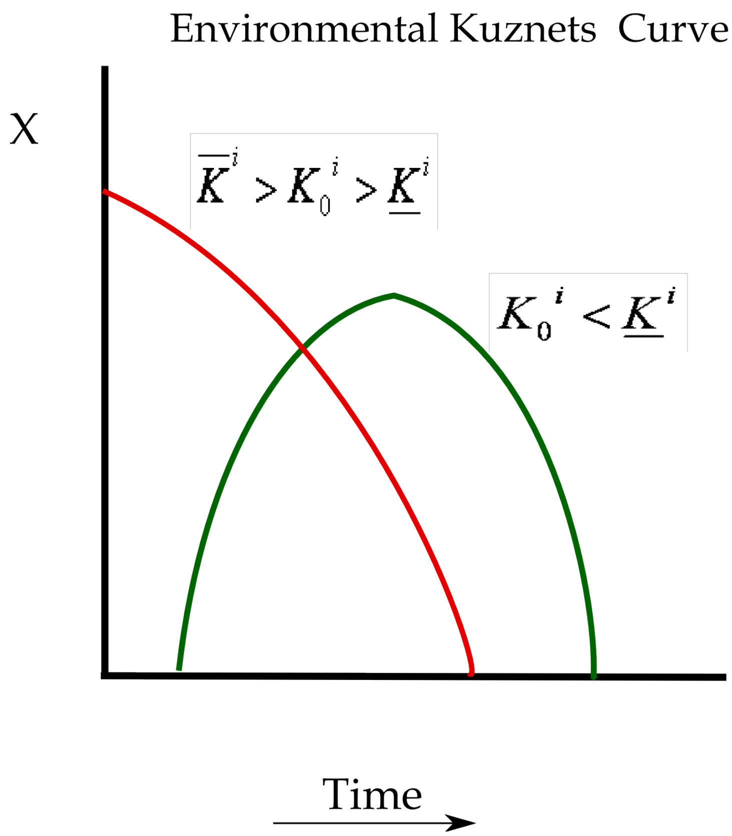

Figure 6.3: environmental Kuznets curve

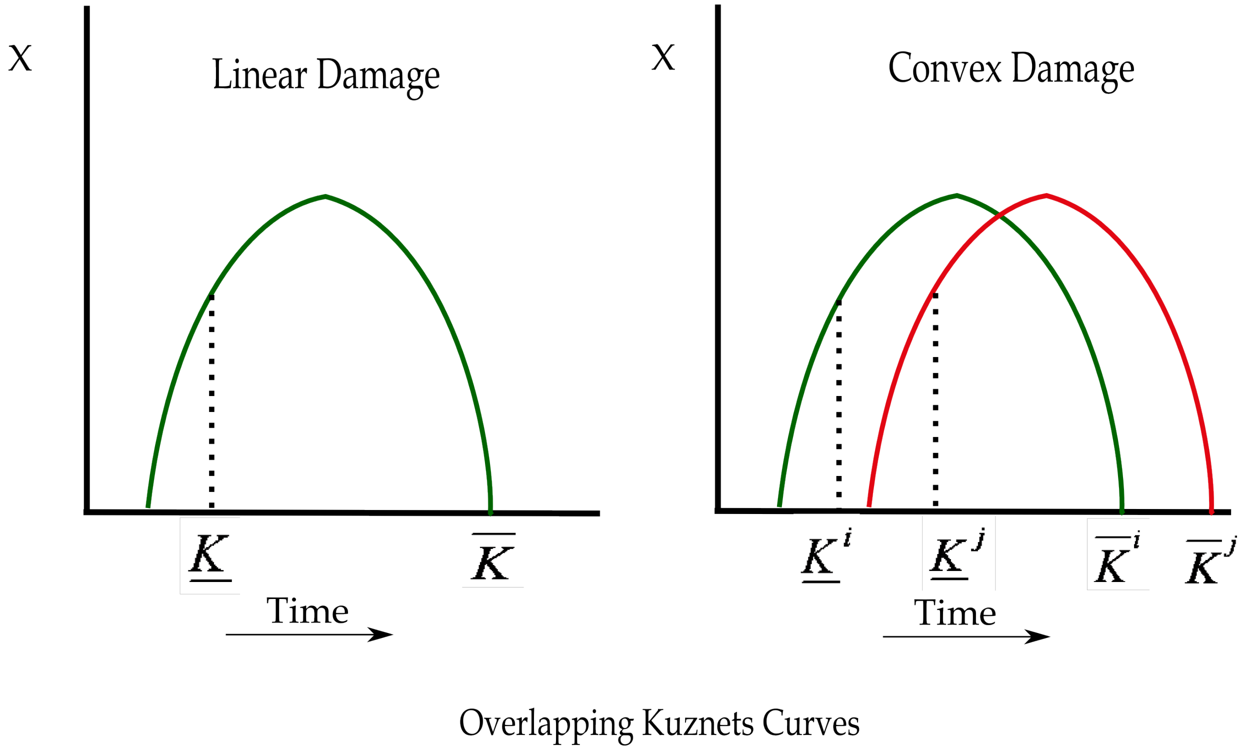

Figure 6.4: Uniqueness of income-pollution path

If the initial level of the capital endowment of a given country i satisfies $K_i(0) < \underline{K}^i$, then the country will always follow an EKC-pattern: pollution increases at low levels of development, but decreases thereafter. If $K_i(0) \in [\underline{K}^i, \bar{K}^i]$ then the country might follow several types of trends. Figure 3 sketches a pattern in which total pollution is continuously declining but other, more intricate patterns might be feasible as well. Note that the graphs in figure 3 are not drawn for any particular parameter choice, but are just a tool in clarifying proposition 4.

With respect to the main indicators of interest related to pollution control, the onset and the maximum, part (ii) of proposition 4 indicates that they are not only related to domestic variables but also to the level of world pollution. Figure 4 relates the shape of the damage function to the income-pollution path:

The left panel of figure 4 sketches the case of a linear damage function with a unique ECK pattern: every country starts abating at the same level of capital and reaches maximum abatement effort at the same level of development as measured by the capital endowment. The panel of the right sketches the situation with country-specific EKC-patterns that emerge under a more general, convex damage function. Here we have sketched a situation with a poor and a rich country, $K_i(0) > K_j(0)$, with the rich country starting abatement at an earlier point in time.

Next, let us define K_P^i as the level of development at which pollution peaks such that $K_0^i \leq \underline{K}^i \leq K_P^i$. Since the level of world pollution itself depends on the distribution of capital and the intensity of abatement across countries, it is not possible, however, to characterize explicitly the path of world pollution or even pollution for a particular country. Nevertheless, the explicit characterization of $\underline{K}^i$ and $\bar{K}^i$ do allow us to focus in more detail on the impact of international trade on these 'timing indicators'. The next lemma summarizes the effects of various parameters on these pollution indicators.

Lemma 2 *The level of development at which pollution control is initiated is (i) increasing in the cost of abatement b, (ii) decreasing in group size n_j, (iii) decreasing in the degree of openness τ and (iv) increasing in the degree of specialization ε.*

Proof Follows directly from $\frac{\partial \underline{K}}{\partial b} = -\frac{\underline{K}}{b} < 0$, $\frac{\partial \underline{K}}{\partial n_j} = -\frac{\underline{K}}{n_j} < 0$, $\frac{\partial \underline{K}}{\partial \tau} = -\frac{1}{\varepsilon}\frac{\underline{K}}{\xi} < 0$ and $\frac{\partial \underline{K}}{\partial \varepsilon} = \frac{\tau}{\varepsilon^2}\frac{\underline{K}}{\xi} > 0$.

Note that feedback effects through the level of world pollution are absent. Since countries are small, parameter changes have a negligible effect on world pollution and so do not affect the onset and maximum of pollution control. This feedback effect would be present, however, if countries are large. A similar lemma can be written for the maximum of pollution control, where $\frac{\partial \bar{K}}{\partial b} = -\frac{\bar{K}}{b-1} < 0$, $\frac{\partial \bar{K}}{\partial n_j} = -\frac{\bar{K}}{n_j} < 0$, $\frac{\partial \bar{K}}{\partial \tau} = -\frac{1}{\varepsilon}\frac{\bar{K}}{\xi} < 0$ and $\frac{\partial \bar{K}}{\partial \varepsilon} = \frac{\tau}{\varepsilon^2}\frac{\bar{K}}{\xi} > 0$.

Next, we discuss how heterogeneity in initial conditions, in combination with the transboundary nature of pollution, can lead to results that seem counterintuitive. Define a leader h as a country with a relatively high (above average) initial stock of capital. Similarly, we define a lagger l as a country with a relatively small initial capital stock. Thus, $K^h(0) > K^l(0)$. In addition, $\underline{K}^h$ ($\underline{K}^l$) then represents the level of development at which a leader (lagger) starts abating. Then consider the following proposition.

Proposition 5 *The advantage of being a leader. With $\gamma > 1$ it is possible that a leader starts abating at a higher level of capital than a lagger country. Formally, there exists initial distributions of capital such that $\underline{K}^h > \underline{K}^l$.*

Proof From the previous proposition we have that $\bar{K}^i$ might vary across countries. By definition a leader h will start abating on the left-hand side on the global environmental Kuznets curve. Now define the maximum that global pollution will obtain as $\bar{D}^w$. Then we have that $\underline{K}^h < \frac{1}{n_j}\frac{1}{b-1}\xi(\bar{D}^w)^{1-\gamma}$. Depending on the initial distribution of capital stocks, there must exist lagging countries for which $\underline{K}^h < \underline{K}^l \leq \frac{1}{n_j}\frac{1}{b-1}\xi(\bar{D}^w)^{1-\gamma}$ or $\underline{K}^h < \frac{1}{n_j}\frac{1}{b-1}\xi(\bar{D}^w)^{1-\gamma} \leq \underline{K}^l$. This completes the proof.

These last two propositions shed new light on the transition of the world economy towards a path with sustainable development under a very simple rule for pollution control. Depending on the specifics of the damage function, rich and poor countries face a different pattern of development with respect to the onset and turning point of local Kuznets curves for emissions. The following figure depicts that this can lead to a situation where a lagger country starts abating at a lower level of capital than a leader:

According to the previous proposition, relatively poor countries are being faced with the need to control pollution in an earlier stage of their development than relatively rich countries. We have showed that this is in fact an optimal decision under the assumptions we have made. Finally, remember that we have assumed the use of just one unique control for pollution in both polluting sectors of production. The following proposition summarizes our results when groups are 'allowed' to use two instruments (θ_N and θ_T), one for each industry.

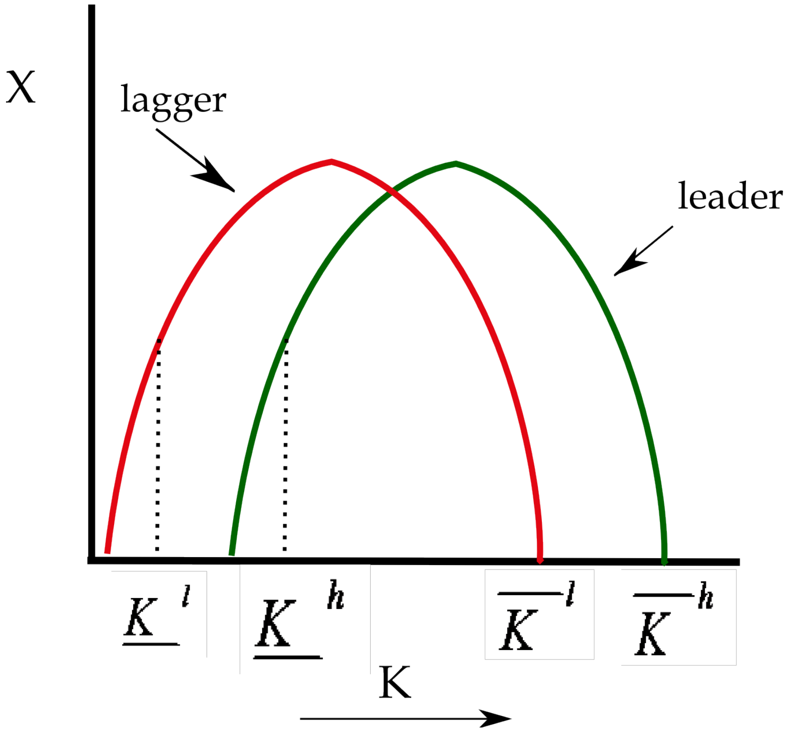

Figure 6.5: Leadership advantage

Proposition 6 *It is optimal for countries to start pollution control in the tradable (non-tradable sector) first if* $\frac{\tau}{1-\tau} < (>) \frac{\varepsilon}{\varepsilon-1}$.

Proof Consider a country that initially does not control pollution. Substitution of $\theta_N = \theta_T = 0$ into $MAC_T^i(\theta_T^i)$ and $MAC_N^i(\theta_N^i)$ and rearranging gives $MAC_T^i(0) < MAC_N^i(0) \Leftrightarrow \frac{\tau}{1-\tau} < \frac{\varepsilon}{\varepsilon-1}$. Since the marginal benefits of each instrument are identical the proposition follows immediately.

According to this proposition emissions will decline first in the tradable sector, given the degree of specialization is high enough and trade openness is low enough. The latter requirement is somewhat unexpected. On the one hand, a high degree of openness means that regulators can export a larger share of abatement costs. On the other hand, it implies that for any given level of abatement intensity a larger proportion of the economy is affected which makes this sector less attractive as a starting point for pollution control. The latter effect dominates. More in general, this result makes clear that the onset of abatement and the turning point of emissions could be related to market structure as well. Future (or existing) empirical work might be able to shed light on this implication of our model. Figure 6 depicts the situation in which, contrary to common wisdom, pollution control starts first in the tradable sector:

In the next section we look at some implications of pollution control for cross-country growth convergence.

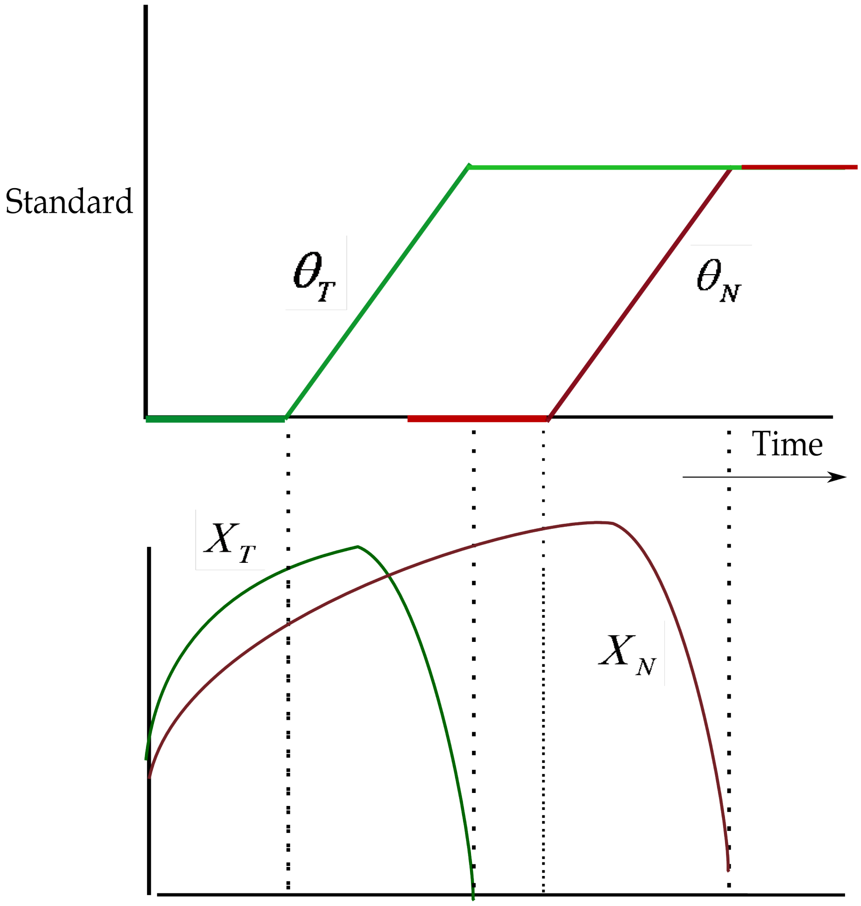

Figure 6.6: Control of pollution in tradable and non-tradable sector

6.5.4 Dynamic Effects of Pollution Control

A common implication of pollution control in growth models is that they create a drag on economic growth rates (see Brock and Taylor, 2005). One way or another, abatement entails the use of productive resources that could otherwise have been used to increase real income. An important question is if and how these costs are shared across countries under international trade. If continuous efforts to limit pollution lower a nation's growth rate can we expect this drag to affect other countries as well? To find out, we substitute real output (6.15) in the budget constraint (6.2), apply $EX = IM$ and $\frac{p_C}{p_I}\frac{C}{K} = \rho$ and rearrange to obtain the growth rate $g \equiv \dot{K}/K$ of capital (and output), $g = \phi(1-\theta_T)p_T(p_N)^{\tau-1} - \rho$. This equation is identical to (6.27) once we assume $\theta_T = \theta_N = \theta$. Using this equation for g, we can substitute from equations (5.5) and (6.14) to obtain the relative growth rate of country i versus country j:

$$\frac{g^i+\rho}{g^j+\rho} = \frac{\phi_i}{\phi_j}\left(\frac{\mu_i}{\mu_j}\left(\frac{1-\theta_T^i}{1-\theta_T^j}\right)^{\varepsilon-1}\frac{K_j}{K^i}\right)^{\frac{\tau}{\varepsilon}}\left(\frac{1-\theta_N^i}{1-\theta_N^j}\right)^{1-\tau} \tag{6.36}$$

Country i has a relatively high rate of growth if it is characterized by a relatively efficient investment technology ($\frac{\phi_i}{\phi_j}$), a relatively efficient intermediate goods technology ($\frac{\mu_i}{\mu_j}$), a relatively low stock of capital ($\frac{K_i}{K^j}$) and relatively loose environmental policy in the tradable sector ($\frac{1-\theta_T^i}{1-\theta_T^j}$) and non-tradable sector ($\frac{1-\theta_N^i}{1-\theta_N^j}$).

Proposition 6 indicates that is optimal to start abating in the tradable sector first provided that $1-\tau > \tau\frac{\varepsilon-1}{\varepsilon}$. In that case, the instaneous marginal cost of abatement are lowest in the tradable sector. A similar argument can be derived from an inspection of the relative rate of growth in (6.36). Here we find that the relative rate of growth is affected to a larger extent by a relative stringent environmental policy in the non-tradable sector than in the tradable sector if and only if $1-\tau > \tau\frac{\varepsilon-1}{\varepsilon}$. Thus, a policy maker that is interested in the relative rate of growth would find it optimal to start abatement in the tradable sector under the same conditions as one that is interested in static considerations only. Intuitively, a small tradable sector and high degree of specialization (low ε) are arguments to initiate more stringent environmental policy in the tradable sector first.

Some further insight with respect to the impact of environmental policy on relative growth rates can be gained under the condition that equation (6.30) holds with strict equality for both countries. Substitution of (6.30) for both countries into (6.36) results in:

$$\frac{g^i+\rho}{g^j+\rho} = \underbrace{\frac{\phi_i}{\phi_j}\left(\frac{\mu_i}{\mu_j}\frac{K_j}{K^i}\right)^{\frac{\tau}{\varepsilon}}}_{\text{identical to AV}}\underbrace{\left(\frac{b_j}{b_i}\frac{n_j}{n_i}\frac{K_j}{K_i}\right)}_{\text{effect of env. policy}}$$

where the first term on the right-hand side shows the orginal AV argument of cross-country convergence (poor countries grow faster) and the second term on the right-hand side includes the novel effects on convergence due to environmental policy. Countries that are part of large groups (n large) and that are

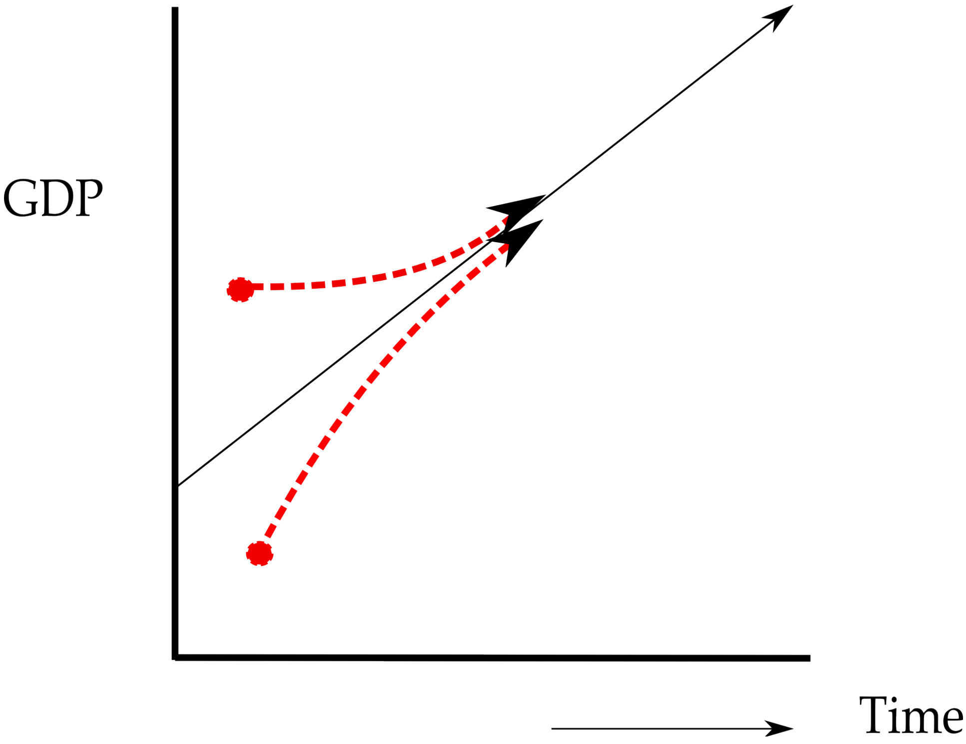

Figure 6.7: Growth Convergence

characterized by efficient abatement technologies (high b) grow relatively slow. This is because being member of a large group and having efficient abatement technologies imply via (6.30) a larger marginal benefit from abatement and thus a more aggressive environmental policy. Also note that in our set-up there is an additional effect of $\frac{K_j}{K_i}$ on relative growth rates. Since rich countries impose a relatively stringent production standard, our analysis shows that we should expect an even faster convergence of cross-country growth rates than in the original AV model.

6.5.5 Implications for Convergence

Using the trade balance equation and the budget constraint one can show that $y = (\mu Y)^{\frac{1}{\varepsilon}}((1-\theta_T)K)^{\frac{\varepsilon-1}{\varepsilon}}$. Obviously, nominal income is increasing in world income and domestic capital, but under diminishing returns. Similarly, abatement in the tradable sector lowers nominal income, again at a diminishing rate. Time differentiating this equation gives:

$$\frac{\dot{y}}{y} = \frac{1}{\varepsilon}g + \frac{\varepsilon - 1}{\varepsilon}[\frac{\dot{\overline{1-\theta_T}}}{1-\theta_T} + \frac{\dot{K}}{K}] \tag{6.37}$$

Next, substitution of $\frac{\dot{K}}{K} = \phi r^{\tau}(1-\theta_N)^{1-\tau} - \rho$, using the definitions of the steady-state relative income y_R^* and the steady state interest rate $r^* = (\frac{g^*+\rho}{\phi})^{\tau}(1-1/b_T)^{\frac{\tau-1}{\tau}}$, we can rewrite the growth rate as (see the appendix):

$$\frac{\dot{y}}{y} = g + \frac{\varepsilon - 1}{\varepsilon}\left(\frac{\dot{\overline{1-\theta_T}}}{1-\theta_T}\right) + \frac{\varepsilon - 1}{\varepsilon}(g^* + \rho)\left[\left(\frac{1-\theta_T}{1-1/b_T}\right)^{\tau}\left(\frac{1-\theta_N}{1-1/b_N}\right)^{1-\tau}\left(\frac{y_R}{y_R^*}\right)^{\frac{-\tau}{\varepsilon-1}} - \frac{g+\rho}{g^*+\rho}\right] \tag{6.38}$$

When $y_R = y_R^*$, $\dot{\overline{1-\theta_T}} = 0$, $1-\theta_T = 1-1/b_T$ and $1-\theta_N = 1-1/b_N$ we find that $\frac{\dot{y}}{y} = (g + (\varepsilon - 1)g^*)/\varepsilon$. A country's growth rate of output is then a weighted average of the world's current rate of growth and the world's steady state rate of growth. Equation (6.38) also reveals that environmental policy puts a drag on economic growth in transition to the steady state, since $\frac{\varepsilon-1}{\varepsilon}\left(\frac{\dot{\overline{1-\theta_T}}}{1-\theta_T}\right) < 0$ and the term $\left(\frac{1-\theta_T}{1-1/b_T}\right)^{\tau}\left(\frac{1-\theta_N}{1-1/b_N}\right)^{1-\tau}$ approaches 1 from above.

Furthermore, one can derive the speed of convergence β to the steady state:

$$\beta \equiv -\frac{dg}{dy}y = \frac{\tau}{\varepsilon}(g^* + \rho)\left(\frac{1-\theta_T}{1-1/b_T}\right)^{\tau}\left(\frac{1-\theta_N}{1-1/b_N}\right)^{1-\tau}\left(\frac{y_R}{y_R^*}\right)^{\frac{-\tau}{\varepsilon-1}} \tag{6.39}$$

The speed of convergence is higher for countries far away from the steady state (low value of $\frac{y_R}{y_R^*}$) and for countries that enforce a lower standard, both in the tradable sector as well as the non-tradable sector (high $\frac{1-\theta_T}{1-1/b_T}$ and high $\frac{1-\theta_N}{1-1/b_N}$). To be precise, from equation (6.39) we learn that abatement (technology) affects the speed of convergence in two ways. First, inefficient abatement technology lowers the steady state world growth rate and thus indirectly slows down convergence. Second, abatement affects the speed of convergence directly via two terms that are of transitory nature. While the static opportunity cost of abatement is the direct loss of foregone output we find that the "dynamic" opportunity cost of abatement is a slower rate of convergence. This aspect of environmental policy might be relevant for policy makers in developing countries interested in catching-up with more advanced economies.

6.6 Conclusion and Discussion

We have constructed a dynamic multi-country growth model with international trade in dirty intermediate goods and implemented a simple rule for pollution control. Within this framework, we have shown the dependency of the marginal cost of abatement on the terms of trade. As emphasized by others, an exporting country will install excessively stringent environmental policy since it does not internalize the costs of environmental policy that are passed through to foreigners in the form of higher prices. Unlike theories of comparative advantage or oligopoly, however, all countries are endowed with this incentive because they are the sole supplier of an unique set of intermediate goods. We explained how the influential monopolistic competition framework bears similar implications for the relationship between trade and the environment. Moreover, since our theory is dynamic in nature, we are able to show how pollution control puts a drag on economic growth and part of this drag is exported to buyers of intermediate goods. In other words, the costs of pollution control on economic growth are partially exported.

We examined the transition to a balanced growth path with sustainable development. Along the transition path, each country experiences an environmental Kuznets curve if its initial capital stock is sufficiently low. There also exists a global Kuznets curve as a result of these overlapping Kuznets curves. Moreover, we explain why, depending on initial conditions and the convexity of the damage function, the path of development is not necessarily unique. In fact, the income pollution path and the peak pollution level most likely vary across countries. The onset of pollution control is also shown to depend upon the degree of openness and the degree to which countries are specialized. Finally, countries have an incentive to differentiate abatement intensity across industries. If the degree of specialization is sufficiently high, emissions decline first in the tradable sectors of the economy.

Future work might deal with issues related to stock pollution, dynamic efficiency and more intricate forms of environmental policy. The story that we have told is one that stresses the importance of economic development and commodity trade in the determination of global pollution trends. In a way, our story is one of succes. Although the world goes through a transition phase with increasing pollution, the result is always the same: in the end there are no limits to growth. In this respect, the equilibrium structure of our model is probably too simple for certain questions. An interesting direction for future research is the construction of models that allow for multiple steady states, including environmental or poverty traps, while still allowing trade, heterogeneity in initial conditions and management of natural resources to play a role in explaining such outcomes. A potential starting point for such an inquiry is given by recent work of Chamon and Kremer (2009). Like Acemoglu and Ventura (2002), Chamon and Kremer (2009) aim to comprehend the (possible) relationships between trade and the long-run world income distribution. However, unlike the AV model the opportunity to develop into a prosperous nation is not guaranteed. Instead, the possibility of a poor country to succeed depends upon its export opportunities which are greater the larger the pool of potential buyers from developed countries. If differences in population growth rates between developed and developing countries are too high, progress in a large part of the developing world could stall and we might observe divergence in the world income distribution. It would be very interesting to apply such a framework to the topic of sustainable development. Perhaps one could investigate how too lengthy periods of poverty and high population growth rates increase the chance of reaching equilibria with unsustainable development or even collapse.

6.6.1 Appendix: Consumption Rule

In the simple benchmark model consumption is a fixed fraction of capital. To attain this result integrate the budget constraint to obtain:

$$\int_0^\infty \frac{p_C}{p_I} C e^{-R(t)} dt = K(0) \tag{6.40}$$

where $R(t) \equiv \int_0^t \frac{r(s)}{p_I(s)} ds$. Next, integrate the Euler equation over $[0, t]$ to find:

$$\int_0^t d\ln\left(\frac{p_C C}{p_I}\right) = \int_0^t \left(\frac{r(\tau)}{p_I(\tau)} - \rho\right) d\tau$$

Rearranging:

$$\frac{p_C(\tau)}{p_I(\tau)}C(\tau) = \frac{p_C(0)}{p_I(0)}C(0)e^{R(t)-\rho t}$$

Substitution into (6.40) and rearranging:

$$p_C(0)C(0) = \rho p_I(0)K(0)$$

More in general, integrating the budget constraint over $[\tau, \infty]$ and the euler equation over $[\tau, t]$ will give us $p_C(\tau)C(\tau) = \rho p_I(\tau)K(\tau)$.

6.6.2 Appendix: Model Characterization

Equations (6.27)-(6.32) in the text can be obtained as follows. Equation (6.27) follows from the investment equation (6.2), $EX = IM$, the definition of R from below equation (6.15) and the application of $\theta_N = \theta_T = \theta$ and $p_T = p_N = p$ such that $R = \phi[(1-\theta)p^\tau]$. Rearranging (6.14) and substitution of $R = \phi[(1-\theta)p^\tau]$ gives us (6.29). Equation (6.29) is identical to equation (6.14) where we have substituted for $P = 1$ and $\theta_T = \theta_N = \theta$. Equation (6.30) follows directly from (6.23) by applying symmetry and noting that the mass of j equals n_j. World pollution (6.31) follows from substitution of $\theta_N = \theta_T = \theta$ in to equation (6.16). Equalization of intermediate goods prices follows from the use of one policy instrument, $\theta_N = \theta_T = \theta$, and gives us (6.32) instead of (6.4).

6.6.3 Appendix: Convergence

Define relative income as $y_R \equiv \frac{y}{Y^w} = \mu(p_T)^{1-\varepsilon}$ where we used (6.14). Steady state relative income y_R^* can then be derived using $\theta_T^* = 1/b_T$ and r^* from (6.33), $y_R^* = \mu(r^*)^{1-\varepsilon}(1-1/b_T)^{\varepsilon-1}$. Furthermore, using these equations for y_R and y_R^* we can rewrite the growth rate and steady state growth rate as $g+\rho = \phi\left(1-1/b_T\right)^\tau\left(1-\theta_N\right)^{1-\tau}(\frac{1}{\mu}y_R)^{-\frac{\tau}{\varepsilon-1}}$ and $g^*+\rho = \phi\left(1-1/b_T\right)^\tau\left(1-1/b_N\right)^{1-\tau}\left(\frac{1}{\mu}y_R^*\right)^{-\frac{\tau}{\varepsilon-1}}$ respectively. Next, rearranging equation (6.37) in the text yields

$$\frac{\dot{y}}{y} = g + \frac{\varepsilon-1}{\varepsilon}\frac{\dot{\overline{1-\theta_T}}}{1-\theta_T} + \frac{\varepsilon-1}{\varepsilon}(g^*+\rho)\left[\frac{1}{g^*+\rho}\frac{\dot{K}}{K} - \frac{g}{g^*+\rho}\right] \tag{6.41}$$

Now substitute $\frac{\dot{K}}{K} = \phi r^\tau(1-\theta_N)^{1-\tau} - \rho$ in (6.41) and use the intermediate results with respect to $g+\rho$ and $g^*+\rho$ to obtain equation (6.38) in the main text.

6.6.4 Appendix: Global Stability

Lemma 1 *The growth rate g is declining during all stages of development.*

Proof In total there are 7 possible stages of development that do no necessarily arise, depending on the initial distribution of capital. These are (1) $u = 1$, (2) $u > 0$, $i > 0$,(3) $i = 1$, (4) $u > 0$, $i > 0$,

$v > 0$, (5) $u > 0$, $v > 0$, (6) $i > 0$, $v > 0$ and (7) $v = 1$. Consider the dynamics of an individual country during the three qualitatively different stages of development:

(A) *Unsustainable Development*. The dynamics of a country in this stage are summarized by $g = \phi r^{\tau} - \rho$ and $rK = \mu r^{1-\varepsilon} Y$. Total differentiating of the trade balance equation shows us that $\frac{dr}{dK} = -\frac{1+y/Y}{\varepsilon - y/Y} r \approx -\frac{r}{\varepsilon} < 0$. Then, the real return on capital in this stage of development, ϕr^{τ}, is falling in K.

(B) *Interior solution for abatement*. The dynamics during this stage are characterized by $g = \phi(1-\theta)p^{\tau} - \rho$. Next to the trade balance condition $rK = \mu p^{1-\varepsilon} Y$ there is an additional static constraint in the form of the policy rule, $\frac{1}{1-\theta}\xi = bn_j (D^w)^{\gamma-1} K$. Total differentiation of the latter shows

$$\frac{d\theta}{dK} = \xi^{-1}(1-\theta)^2 bn_j (D^w)^{\gamma-1}$$

Next, differentiate the trade balance equation to obtain

$$r[1-\mu(p)^{1-\varepsilon}]dK = [(1-\varepsilon)\mu(p)^{-\varepsilon}Y](\frac{1}{1-\theta}dr + \frac{p}{1-\theta}d\theta) + [\mu(p)^{1-\varepsilon} - 1]Kdr$$

Substitution of $\frac{d\theta}{dK}$ into this equation and rearranging gives us

$$\frac{dr}{dK} = \frac{-r[1-\mu(p)^{1-\varepsilon}] - r[(\varepsilon-1)\mu(p)^{-\varepsilon}Y]\frac{d\theta}{dK}}{(\varepsilon-1)\mu(p)^{-\varepsilon}Y\frac{1}{1-\theta} + (1-\mu(p)^{1-\varepsilon})K} < 0$$

Finally, differentiate g with respect to θ and r, and substitute the derivatives $\frac{d\theta}{dK}$ and $\frac{dr}{dK}$ to find:

$$\frac{\partial(\phi[(1-\theta)p^{\tau}])}{\partial K} = -\phi p^{\tau}[(1-\tau(1-\theta)^2)\frac{d\theta}{dK} - \tau\frac{1}{p}\frac{dr}{dK}] < 0$$

Again, the real return on capital is falling in K. (C) *Sustainable development*. The dynamics during this stage are characterized by $g_K^i = \phi(1-1/b)^{1-\tau} r^{\tau} - \rho$ and $rK = \mu(1-1/b)^{\varepsilon-1} r^{1-\varepsilon} Y$. Total differentiation shows that again $\frac{dr}{dK} = -\frac{1+y/Y}{\varepsilon-y/Y} r \approx -\frac{r}{\varepsilon} < 0$. It follows that the real return to capital during this stage, $\phi(1-1/b)^{1-\tau} r^{\tau}$, is again falling in K. This completes the proof.

6.6.5 Appendix: No Abatement Decisions and Exogenous Decline in Emission Intensity

Crucial assumptions of our model are (i) the lack of technological progress and (ii) the endogeneity of the abatement assumption. Brock and Taylor (2010) amend the Solow model by incorporating technological progress in abatement while assuming that the fraction of gross output directed to abatement purposes is constant. In a similar vein suppose that the emission intensity is declining at an exogenous rate of growth denoted by g_A:

$$z_T(t) = z_{T,0} e^{-g_A t}$$

$$z_N(t) = z_{N,0} e^{-g_A t}$$

where emission intensities in the tradable and non-tradable sector, $z_T(t)$ and $z_N(t)$, are assumed to decline at an equal rate. The flow of pollution $Z^i(t)$ in country i at time t is then given by $Z^i(t) = [z_T(t)\tau + z_N(t)(1-\tau)]K^i(t)$, and global pollution is again the sum of pollution over all countries, $Z^w = \int Z^i(t)di$. The current-value Hamiltonian for each individual country is defined as $H(C, K, \theta) = \ln C - \eta Z^w + \lambda[\phi r^\tau K - \frac{p_C}{p_I}C]$, which leads us to the following necessary first-order conditions:

$$\frac{\partial H}{\partial C} = 0; \quad \frac{1}{C} = \lambda \frac{p_C}{p_I} \tag{6.42}$$

$$\dot{\lambda} - \rho\lambda = -\frac{\partial H}{\partial K}; \quad \dot{\lambda} - \rho\lambda = -\lambda\phi r^\tau \tag{6.43}$$

where the second equation is derived by noticing that each country has a negligible impact on world pollution and therefore take world pollution as given. From the first-order condition (6.42) we derive the growth rate of consumption, $g_C = \frac{\dot{C}}{C} = \phi r^\tau - \rho$. The current-value Hamiltonian for the social optimum, i.e. cooperative solution, reads

$$H = \int [\ln C^i - \eta Z^w]di + \int \{\lambda^i[\phi(r^i)^\tau K^i - \frac{p_C^i}{p_I^i}C^i]\}di$$

where we used superscript i to differentiate between all countries. The first term is social welfare, $V^w = \int v^i di$, whereas the second term is simply the summation over all (investment) constraints. This then leads to the following FOC's:

$$\frac{1}{C^i} = \lambda^i \frac{p_C^i}{p_I^i}$$

$$\dot{\lambda}^i - \rho\lambda^i = -\lambda^i\phi(r^i)^\tau + \eta[\tau z_T + (1-\tau)z_N]$$

where this set of equations holds for all countries. The Euler equation for country i now reads $g_C^S = \left(\frac{\dot{C}}{C}\right)^S = \phi r^\tau - \rho - \phi\eta z_0 e^{-g_A t}C$ where S is used to denote the social optimum and where $z_0 \equiv \tau z_{T,0} + (1-\tau)z_{N,0}$ is the normalized pollution level at time $t = 0$. Introducing a production tax ϑ in each country, we can equalize $g_C^S = g_C$ by implementing the following tax in each country:

$$\vartheta = \eta \frac{C}{r^\tau} z_0 e^{-g_A t} \tag{6.44}$$

Total differentiation of (6.44) then reveals that the rate of growth of the production tax in each country follows the following equation:

$$\frac{\dot{\vartheta}}{\vartheta} = \frac{\dot{C}}{C} - \tau\frac{\dot{r}}{r} - g_A \tag{6.45}$$

showing us that taxes are not identical across countries. Further substitution of $g_C = \frac{\dot{C}}{C} = \phi r^\tau - \rho$ into (6.45) shows $\frac{\dot{\vartheta}}{\vartheta} = (1-\vartheta)\phi r^\tau - \rho - \frac{\tau}{\varepsilon}(g - g_K) - g_A$ where g is the growth rate of world income, which equals g^* in equilibrium. Note that we used $r^\varepsilon = Y/K$ to obtain $\varepsilon \frac{\dot{r}}{r} = g - g_K$. On a balanced growth path we have $g - g_K = 0$ and $g = g^*$ such that:

$$g_\vartheta^* = g^* - g_A$$

which tells us that on the balanced growth path, in order to implement the social optiumum, the domestic emission tax should grow at a positive rate as long as the growth rate of output exceeds the growth rate of abatement technology.

Chapter 7

Conclusion and Discussion

In what follows I will shortly discuss some of the main findings of this thesis. To structure this analysis, I will group these findings along two different themes that run through this thesis. These two themes cover all chapters, except for chapter 4. The themes considered here are:

1. Trade, Growth and the Environment (Chapter 3 and Chapter 6).
2. Cross-Country Interdependencies and the Environment (Chapter 2, Chapter 5 and Chapter 6).

Part 1. Trade, Growth and the Environment.

Chapter 3 and chapter 6 of this thesis focused on the interplay between trade, growth and the environment. Both transitional dynamics and long-run behavior, using dynamic models, were analyzed. In the remainder I will discuss some of our findings with respect to the long-run, and then shift to discuss transitional dynamics. I conclude with some suggestions for future research and how they relate to the assumptions made in this thesis.

In the very long-run the analysis in chapter 3 shows us, using a dynamic H-O model, that there is convergence in pollution levels but not in terms of national income. Furthermore, the world level of pollution is identical across all steady states and therefore independent of the pattern of trade. So even though the results with respect to pollution are pretty 'comforting' in the sense that there are no real pollution havens, differences in income and the pattern of trade remain. We also found that differences in the social discount rate across countries lead to sharper specialization patterns and that the impatient country will always be a pollution haven, i.e. an exporter of the dirty commodity. In chapter 6 we found, similar to chapter 3, that economic growth will not lead to income convergence. Since the model features a balanced growth path we do observe growth convergence. More interestingly, pollution continuously declines in the long-run after an initial phase of increasing pollution. This global environmental Kuznets curve is essentially a story of success. The assumed technology is key here: increasing returns to scale in abatement basically provide the means for a scenario with sustainable development.

Next to an analysis of the long-run, chapter 6 also provided insights on the transitional dynamics of local and global pollution patterns. It is shown that, along the transition path, each country experiences an environmental Kuznets curve if its initial capital stock is sufficiently low. Consequently, there also exists a global Kuznets curve as a result of these overlapping Kuznets curves. Moreover, we explain why, depending on initial conditions and the convexity of the damage function, the path of development is not necessarily unique. In fact, the income pollution path and the peak pollution level most likely vary across countries. The onset of pollution control is also shown to depend upon the degree of openness and the degree to which countries are specialized. Finally, countries have an incentive to differentiate abatement intensity across industries. If the degree of specialization is sufficiently high, emissions decline first in the tradable sectors of the economy. Another interesting finding relates to the fact that stringent environmental policy leads to a lower rate of convergence. This lower rate of convergence might be interpreted as the 'dynamic opportunity cost of abatement'. It complements the concept of the static opportunity cost of abatement, which is defined as the direct or instantaneous cost of foregone output. This aspect of environmental policy might be relevant for policy makers in developing countries that are striving to catch-up with developed countries.

Discussion

There are various avenues for future research that could extend and improve upon some of the approaches used in this thesis. When presenting these ideas, we will progressively move from suggestions that are close to the content of this thesis to ones that require more thought making them tangible.

First, we have not yet analyzed the transitional dynamics of pollution in a H-O world. Studying transitional dynamics in the H-O model is not a trivial exercise. Only very recently, assuming specific functional forms, was Caliendo (2010) able to fully characterize transitional dynamics of a two-sector two-factor two-country H-O model. One might be able to build on his work to further study the interrelationship between factor accumulation, local and global environmental policies, and environmental outcomes in a world with international trade.

Second, in chapter 3 we assumed that there were only two factors of production, capital and emissions. In addition, the supply of both factors was assumed "flexible". These assumptions, albeit stark, allowed us to stay within the comfortable two-factor two-sector two-country setting. As is well-known in the trade literature, many of the results that hold in this setting need to be modified for higher dimensions. A more practical objection relates to the steady state outcome of the model presented in chapter 3. We find that all steady state variables, including world pollution, are strictly a function of parameters related to technology and preferences, but not of endowments. Since in reality natural resources and environmental resources are finite, one would expect these natural constraints to somehow bear on the steady state. Introducing labor and/or land as an additional factor of production might be a relatively straightforward manner to do this.

Third, chapter 3 builds on the interesting but complex assumption of multiple forward-looking agents. In each country, the social planner maximizes intertemporal welfare by choosing consumption and environmental policy. This implies that policy makers need to understand the whole future path of emissions, national income etc. to make current decisions. To characterize the model completely, we must know the entire distribution of economic activity over the various countries for each feasible action. This aspect of multiple forward-looking agents is one of the reasons that prevent us from analyzing the transitional dynamics of the model. As Desmet and Rossi-Hansberg (2010) explain in an intriguing paper on spatial dynamics, one way around this problem is to impose enough structure on the model such that agents effectively make static decisions. In chapter 6, we have assumed that agents make static decisions regarding environmental policy, but there might be more theoretically appealing ways to introduce static-decision making. One way or another, the imposed structure must imply that the costs and benefits of environmental policy must not depend directly on future variables.

Fourth, dynamic models of trade and the environmental could also benefit from a more sophisticated view of abatement technology. For example, in chapter 6 we simply assumed that abatement technology was subject to increasing returns to scale and all countries would eventually implement clean production technologies. In practice, the implementation of clean technologies is likely to be preceded by long phases of investment in research and development, subject to all sorts of uncertainties. It would be interesting to add stochastic technological progress in a multi-country setting. Likewise, one should consider the idea that only countries that are sufficiently close to the knowledge frontier can improve upon currently available abatement technologies. In this way, one would expect that technological progress is likely to improve relatively slowly in a world with a skewed global income distribution. This could prove for a new interesting relationship between inequality and global environmental quality.

Fifth and finally, another interesting direction for future research is the construction of models that allow for multiple steady states, including environmental or poverty traps, while still allowing trade, heterogeneity in initial conditions and management of natural resources to play a role in explaining such outcomes. A potential starting point for such an inquiry is given by recent work of Chamon and Kremer (2009). Like Acemoglu and Ventura (2002), Chamon and Kremer (2009) aim to comprehend the (possible) relationships between trade and the long-run world income distribution. However, unlike the AV model the opportunity to develop into a prosperous nation is not guaranteed. Instead, the possibility of a poor country to succeed depends upon its export opportunities which are greater the larger the pool of potential buyers from developed countries. If differences in population growth rates between developed and developing countries are too high, progress in a large part of the developing world could stall and we might observe divergence in the world income distribution. It would be very interesting to apply such a framework to the topic of sustainable development. Perhaps one could investigate how too lengthy periods of poverty and high population growth rates increase the chance of reaching equilibria with unsustainable development or even collapse.

Part 2. Cross-Country Interdependencies and the Environment

International trade in consumption goods constitutes an important dimension by which nations states are interconnected. In this thesis, however, we also pay attention to other economic interdependencies, namely factor mobility, international factor ownership, trade in intermediate goods and vertical integration, and analyze their implications for environmental policies and environmental quality. Let us represent our findings again, arranged by (i) factor mobility, (ii) international factor ownership and (iii) trade in intermediate goods with vertical integration.

First, whether the optimal tax on the natural resource, e.g. land in chapter 2, is suboptimal high or low is dependent upon the question whether the country is a net importer or net exporter of capital. A capital importer can increase its land tax to extract rents from the capital exporter, the extent to which is limited by capital mobility. Similarly, a capital exporter will lower its domestic land tax to increase the world interest rate on capital in order to increase its capital payments from abroad. Again, this incentive is limited due to full capital mobility.

Second, under international factor ownership (e.g. foreign companies own a certain share of the domestic capital stock) we find that a part of the costs from environmental policy are directly borne by foreigners. As a result, domestic policy makers are likely to implement excessively stringent environmental policy, ignoring other considerations. The crucial assumption here is that the degree of ownership is given and unresponsive to environmental policy. Although neither full factor mobility, as in chapter 2, nor complete unresponsiveness, as in chapter 5, are likely to hold in practice, they provide for two extreme benchmark cases that might be informative when evaluating real world policies.

Third, if the degree to which export goods are produced with imported goods increases (i.e. a higher degree of vertical integration), then we show, both numerically and analytically, that global pollution can decrease. This ambiguity arises from the interaction of direct and indirect changes in (i) total factor productivity, (ii) environmental standards and (iii) the elasticity of global pollution with respect to environmental policy. Trade in intermediate goods also implies that carbon leakage can actually be negative. This finding contrast sharply with earlier results in the literature that stressed that unilateral environmental policy is likely to be less effective in a world with international trade due to positive carbon leakage. We should note, however, that the robustness of this result should be analyzed further in more general models.

Discussion

Perhaps one of the most interesting findings in chapter 5 is that certain aspects of globalization, e.g. the vertical integration of the world economy as well as international factor ownership, can actually diminish the negative effects of free-riding on global environmental quality. The model in chapter 5 had several special assumptions, some of which were merely made in the interest of obtaining analytical results. Others might prove to be mere crucial for our results. To analyze the sensitivity of our results some aspects that might be introduced in future work are: multiple factors of production, trade in intermediate goods as well as trade in final consumption goods, increasing returns to scale under monopolistic competition and country asymmetries.

Another avenue for future research relates to what we have called the desensitization of local environmental policy. In chapter 5 we explained how certain aspect of globalization might lead to an increasing insensitivity of local pollution with respect to domestic policy standards. More broadly, globalization might (or might not) lead to a situation where local environmental quality is to a decreasing extent determined by local determinants, including domestic regulations. Note that this is neither directly related to transboundary pollution, nor should this be considered a trivial observation. To see why, consider the closely related topic of 'factor insensitivity' that has recently re-emerged in the trade literature.

An old but important question in trade theory is how factor prices are determined under international trade and, more specifically, how sensitive they are either to changes in domestic and international supplies of production factors. The benchmark case under international trade is that of imperfect specialization and factor price equalization, where factor prices are completely insensitive to local factor supplies. This factor insensitivity result breaks down or is weakened under more general assumptions regarding trade costs and market structure. Recently, Trefler and Zhu (2010) and Burstein and Vogel (2011) reconsider the factor insensitivity result in more general settings with an international input-output structure of production and trade costs. In a similar way, their work might inspire new work on the related question how in general local environmental quality (and prices of natural resources) are determined by local and non-local determinants. Not only might progress in this area shed light on the closely related issue of carbon leakage, it might also provide for a more solid theoretical foundation to the recent surge in the literature on empirical environmental input-output analysis. Furthermore, research in this area might shed light on questions related to the embodiment of carbon dioxide in international trade flows and its implications for policy and global welfare.

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Samenvatting (Summary in Dutch)

Internationale handel biedt landen de mogelijkheid tot het invoeren van goederen en diensten die zij niet zelf of enkel tegen relatief hoge kosten kunnen produceren. Door internationale handel kunnen landen zich specialiseren in de productie van een beperkt aantal goederen en hiermee de verschillen tussen landen uitbuiten. Dit betekent dat elk land zich richt op de productie van goederen waar het een comparatief voordeel in heeft, dat wil zeggen, die goederen die het land relatief goedkoop kan produceren. Onder bepaalde omstandigheden leidt handel bovendien tot een groter aanbod van verschillende producten.

De laatste jaren bestaat er echter ook meer aandacht voor de nadelen van internationale handel. Internationale handel kan leiden tot een lagere milieukwaliteit wanneer handel gepaard gaat met een hogere economische groei en deze groei niet wordt vergezeld van strenger milieubeleid of milieuwetgeving. Bovendien kunnen nationale overheden en beleidsmakers, in een wereld die in steeds grotere mate wordt gekarakteriseerd door vrijhandel, in de verleiding komen om milieubeleid te gebruiken voor andere doeleinden dan bescherming van de leefomgeving. Men kan hierbij denken aan het verzwakken van milieubeleid teneinde de concurrentiepositie van het bedrijfsleven op internationale markten te verbeteren.

In dit proefschrift wordt stil gestaan bij een aantal deelaspecten van de relatie tussen internationale handel en het milieu. De aandacht gaat onder meer uit naar de volgende vragen:

(i) *Kunnen verschillen in milieubeleid tussen landen leiden tot het ontstaan van zogenaamde "pollution havens" in arme landen?* De "pollution haven hypothese" stelt dat arme landen gekenmerkt worden door lagere normen op het gebied van milieubeleid en daarom een thuishaven bieden voor vervuilende industrieën. In een situatie van vrijhandel zullen vervuilende industrieën zich verplaatsen naar arme landen. Dit betekent dat arme landen zich dan zullen toeleggen op de productie en export van vervuilende goederen. De nadruk in dit proefschrift ligt onder meer op de dynamiek omtrent het ontstaan van "pollution havens". Nemen we een model in ogenschouw met daarin een rol voor economische groei, krijgen we op de lange termijn dan dezelfde uitkomst als in eerdere theorieën waarin voor economische groei geen plaats is?

(ii) *Wat is de relatie tussen de hoogte van het inkomen (per hoofd van de bevolking) en de mate van milieuvervuiling? Op wat voor wijze spelen internationale handel en economische groei een rol in deze relatie?* In dit proefschrift concentreren wij ons op het construeren van een economisch model waar economische groei, milieubeleid en internationale handel elkaar wederzijds beïnvloeden.

(iii) *In hoeverre biedt internationale handel een land de mogelijkheid de kosten van milieubeleid* *af te wentelen op zijn handelspartners in de vorm van hogere prijzen?* We proberen deze vraag te beantwoorden in de context van internationale handel in intermediaire goederen. Het betreft hier een vorm van handel die relatief weinig aandacht heeft gekregen in de literatuur, maar empirisch gezien erg belangrijk is.

(iv) *In hoeverre kan corruptie internationale handel verminderen?* Handelsbarrières spelen nog altijd een grote rol bij het bepalen van de omvang van handelsstromen. Hier verrichten we empirisch onderzoek naar corruptie als een belemmerende factor voor de omvang van bilaterale handelsstromen. Onder corruptie wordt in dit proefschrift verstaan corruptie bij de douane, bijvoorbeeld in de vorm van het aannemen van steekpenningen door werknemers van de douane.

Naast het eerste, inleidende hoofdstuk bevat dit proefschrift 5 hoofdstukken. In de rest van de samenvatting wordt nader op deze laatste 5 hoofdstukken ingegaan.

Internationale Handel en het Milieu

In het tweede hoofdstuk van dit proefschrift analyseren we de implicaties van economische integratie voor bescherming van regionale en wereldwijde biodiversiteit. Het niveau van biodiversiteit in elk land hangt af van de omvang van habitatgebied voor flora en fauna. Wereldwijde biodiversiteit is gerelateerd aan biodiversiteit in de afzonderlijke landen en het is mogelijk dat er een zekere mate van overlap in soortenrijkdom tussen landen bestaat. Bescherming van habitatgebied is niet zonder problemen, omdat land ook voor veel menselijke doeleinden gebruikt kan worden. Men kan hierbij denken aan het belang van voldoende land voor de productie van landbouwproducten. Er bestaat dus een afruil tussen land voor menselijk gebruik en biodiversiteit door middel van habitat bescherming.

Het beschermen van biodiversiteit is een belangrijk probleem voor ontwikkelingslanden (Zuid), die er bij gebaat zijn zoveel mogelijke kapitaal uit ontwikkelde landen (Noord) aan te trekken. Daarbij kan streng natuurbeleid het aantrekken van buitenlands kapitaal bemoeilijken. Tegelijkertijd is bescherming van biodiversiteit om diverse redenen zeer belangrijk en moet biodiversiteit gezien worden als een wereldwijd publiek goed.

We construeren een simpel twee landen model met drie productiefactoren, te weten arbeid, kapitaal en land. We modellen economische integratie als een afname van inefficiënties in kapitaalmarkten in Zuid, waarna kapitaal van Noord naar Zuid vloeit. Mobiliteit van kapitaal is een belangrijk aspect van globalisering en heeft in de literatuur over de relatie tussen handel en milieu nog relatief weinig aandacht gekregen.

Het blijkt dat wanneer landen op non-coöperatieve wijze hun landbeleid bepalen zij daarbij rekening houden met het feit dat meer biodiversiteit in het ene land de baten van meer biodiversiteit in eigen land verlaagt. Dit doet zich voor wanneer er een overlap bestaat in soortenrijkdom tussen landen. We noemen dit een "diversity induced substitution effect". Deze prikkel, die wezenlijk verschilt van het welbekende free-rider probleem, impliceert dat landen ceteris paribus minder land zullen reserveren voor habitatgebied dan wanneer zij hier gezamenlijk over zouden beslissen. Investeringen van Noord in Zuid kunnen welvaartsverhogend werken voor Zuid als het landbeleid optimaal is. We spreken van optimaal landbeleid wanneer de prijs van land gelijk is aan de marginale substitutieverhouding tussen biodiversiteit en consumptie. Eveneens blijkt dat in de second-best oplossing, waarbij landen hun gezamenlijke welvaart maximaliseren, het over het algemeen niet optimaal is om voor gelijke marginale kosten van habitat bescherming te kiezen in beide landen. Immers, wanneer rechtstreekse transfers tussen landen niet mogelijk zijn dan laat de second-best oplossing zien dat, omwille van de internationale inkomensverdeling, de mate van habitat bescherming in Zuid wordt verlaagd om de materiële productie en consumptie daar te verhogen.

Het derde hoofdstuk van deze thesis gaat in op de vraag in hoeverre verschillen in milieubeleid ervoor kunnen zorgen dat arme landen zich zullen specialiseren in de productie van vervuilende goederen. In tegenstelling tot eerdere bijdragen aan de literatuur formuleren wij een model waarin expliciet rekening wordt gehouden met economische groei. De belangrijkste contributie van het derde hoofdstuk is dan ook het bieden van een dynamische perspectief op de "pollution haven hypothesis". Het model in dit hoofdstuk gaat uit van twee landen en twee goederen, waarvan één goed relatief vervuilend is. Landen kunnen een gedeelte van het nationaal inkomen gebruiken om te sparen. Besparingen worden gebruikt voor het vergroten van de kapitaalvoorraad, zodat in de toekomst meer geproduceerd en geconsumeerd kan worden. De mate waarin consumenten bereid zijn consumptie vandaag in te ruilen voor meer consumptie in de toekomst zal afhangen van de hoogte van de rentevoet en de hoogte van de subjectieve tijdsvoorkeur. Hoewel een volledige karakterisering van het model buiten het bestek van deze thesis gaat, kunnen wij wel ons wel richten op een analyse van het lange termijn evenwicht.

Wij vinden onder meer dat op de lange termijn een groot aantal verschillende evenwichten mogelijk is. In tegenstelling tot wat soms wordt verwacht, betekent dit ook dat op de lange termijn verschillen tussen landen blijven bestaan. Toch zijn er ook belangrijke overeenkomsten. Hoewel landen in termen van materiële welvaart uiteen lopen, laat dit model zien dat de milieukwaliteit in beide landen op de lange termijn aan elkaar gelijk is. Er treedt dus convergentie op in termen van milieukwaliteit, maar niet in termen van materiële welvaart en consumptie. Uit toekomstig onderzoek moet blijken in hoeverre dit een robuuste uitkomst is in dynamische handelsmodellen met een rol voor milieubeleid. Onder wat voor omstandigheden impliceert convergentie in inkomen ook convergentie in termen van vervuiling en vice versa? Ook vinden we dat wanneer landen verschillen in termen van de subjectieve tijdsvoorkeur van consumenten er eerder specialisatie in productie optreedt. Een land met een hogere tijdsvoorkeur voet zal minder geneigd zijn tot het uitstellen van consumptie nu om, door middel van een hoger niveau aan besparingen, meer consumptie in de toekomst te realiseren. Het land met een hogere tijdsvoorkeur zal op de lange termijn een exporteur van vervuilende goederen zijn, omdat het relatief kapitaal arm is ten opzichte van het geduldige land.

De invloed van corruptie op internationale handel staat centraal in het vierde hoofdstuk van dit proefschrift. Onze hypothese is dat internationale corruptie tot een vermindering leidt van bilaterale handelsstromen. Deze stelling is interessant omdat eerder onderzoek heeft aangetoond dat het volume van internationale handel in de wereldeconomie veel lager is dan we op basis van economische theorie zouden verwachten. Deze puzzel, 'the mystery of missing trade' (Trefler, 1995), is in verband gebracht met diverse soorten handelsbarrières, zowel kunstmatig als natuurlijk, die nog steeds tussen landen bestaan. In hoofdstuk 3 richten we ons op corruptie als potentieel obstakel voor bilaterale handel. In tegenstelling tot eerder studies gebruiken we voor ons empirisch onderzoek indicatoren voor corruptie die rechtstreeks aan handel gerelateerd zijn in plaats van algemene indicatoren. Bovendien weerspiegelen deze indicatoren feiten en ervaringen, en zijn om die reden verschillend van andere indicatoren voor corruptie, die meer gebaseerd zijn op percepties. Als empirisch model hanteren we het zogenaamde graviteitsmodel, wat inmiddels is uitgegroeid tot meest gebruikte empirische model op het terrein van internationale handel. Het graviteitsmodel voorspelt handelsstromen tussen landen op basis van de omvang van landen, vaak gemeten in termen van het bruto nationaal product, en de fysieke afstand tussen landen. Hoe kleiner de afstand en hoe de groter de landen in kwestie, des te groter zouden de bilaterale handelsstromen tussen landen moeten zijn. Met behulp van dit model kijken we onder meer naar de invloed van corruptie op het niveau van internationale handel tussen landen. Ook zijn we geïnteresseerd in de vraag in hoeverre corruptie faciliterend kan werken als landen worden gekenmerkt door slechte instituties. De gedachte hier is dat corruptie een hoger niveau van handel tussen landen mogelijk maakt, wanneer inefficiënte instituties een grote belemmering vormen voor handelsstromen.

Onze analyse laat het belang zien van het gebruik van variabelen voor corruptie en instituties die rechtstreeks gerelateerd zijn aan internationale handel in plaats van maatstaven voor algemene corruptie. De resultaten die wij vinden wijken af van de resultaten voor algemene corruptie. Zo vinden wij dat algemene corruptie een belemmerende werking heeft voor internationale handel, maar het betalen van steekpenningen aan de douane daarentegen kan de import verhogen. Deze interpretatie van corruptie als een soort smeermiddel is het meest robuust voor het importerende land en wanneer er sprake is van een inefficiënte douane. Eveneens vinden we dat lange wachttijden voor het invoeren van goederen aan de grens een significant negatief effect heeft op internationale handel. Onze studie bevat ook maatstaven die iets vertellen over de onvoorspelbaarheid/onzekerheid betreffende corruptie. Onzekerheid met betrekking tot corruptie is belangrijk, omdat het hier gaat om een risico in plaats van een voorspelbare kostenpost. De resultaten op dit gebied zijn echter onduidelijk.

In hoofdstuk 5 gaan we in de op de vraag in hoeverre internationale handel landen de mogelijkheid biedt om een gedeelte van de kosten van milieubeleid op het buitenland af te wentelen. Deze vraag is relevant omdat een belangrijke stroming binnen de literatuur verondersteld dat internationale handel en een schoon milieu niet compatibel zijn. Immers, internationale handel dwingt overheden om het milieubeleid af te zwakken zodat binnenlandse bedrijven concurrerend kunnen zijn op internationale markten. Het blijkt dat deze negatieve kijk op handel en milieubeleid niet de enige mogelijke uitkomst is. Als handel gebaseerd is op de uitruil van unieke goederen dan kunnen overheden, afhankelijk van de prijselasticiteit van de vraag, een strenger milieubeleid hanteren wetende dat bedrijven hogere prijzen zullen doorspelen aan buitenlandse consumenten. Overheden die non-coöperatief hun milieubeleid vaststellen zullen bij een kosten-batenanalyse van deze maatregelen alleen rekening houden met de negatieve welvaartseffecten van hogere prijzen voor de eigen consument. Dit betekent dat wanneer een land veel handel met het buitenland drijft, beleidsmakers een groot deel van de kosten van milieubeleid niet mee zullen nemen in hun afweging welk type milieubeleid, streng of zwak, men moet implementeren. In dit hoofdstuk laten we zien dat dit kan leiden tot een zogenaamde "race-to-the-top" in plaats van een "race-to-the-bottom", wat betekent dat milieubeleid wellicht te streng is in vergelijking tot wat optimaal is vanuit een globaal welvaartsperspectief.

Dit hoofdstuk draagt eveneens bij aan de literatuur doordat de analyse plaats vindt in een model waarin landen handelen in intermediaire goederen. Handel in intermediaire goederen is empirisch gezien belangrijk: meer dan 50% van het wereldhandelsvolume kan worden toegeschreven aan handel in intermediaire goederen. Een intermediaire goed kan worden gedefinieerd als een geproduceerd goed dat als input dient voor een bepaald productieproces en dat, in tegenstelling tot kapitaal, wordt verbruikt in het productieproces. Internationale handel wordt dus gedomineerd door handel in goederen die niet direct geconsumeerd worden maar weer als input dienen in een productieproces voor andere goederen en diensten. Handel in intermediaire goederen gaat ook vaak gepaard met een zogenaamde input-output structuur. Dit betekent dat intermediaire goederen, waarvan een groot gedeelte is bestemd voor de export, worden geproduceerd met behulp van andere geïmporteerde intermediaire goederen. Het model in hoofdstuk 5 ondervangt ook dit aspect van handel in intermediaire goederen. Men zou kunnen stellen dat globalisering in belangrijke mate wordt gekarakteriseerd door een toename van de mate waarin export goederen worden geproduceerd met geïmporteerde goederen. We laten zien dat dit aspect van globalisering een goede uitwerking kan hebben op de wereldwijde milieukwaliteit: de kosten van milieubeleid voor het buitenland nemen toe terwijl overheden geen prikkel hebben om deze effecten mee te wegen in hun besluiten ten aanzien van milieubeleid.

Een ander interessant punt is het gegeven dat handel in intermediaire goederen kan leiden tot negatieve "carbon leakage". Carbon leakage doet zich voor wanneer slechts een beperkt aantal landen besluit over te gaan tot strenger milieubeleid. In een dergelijk geval kan een gedeelte van de baten van strenger milieubeleid, dat wil zeggen minder milieuvervuiling, weg lekken doordat de vervuiling in andere landen toeneemt. Er zijn verschillende redenen waarom dit fenomeen kan optreden. Een belangrijke reden is dat de prijsverhogende werking van een streng milieubeleid een prikkel geeft aan bedrijven in landen met een zwakke regelgeving om de productie op te voeren. In het geval van intermediaire goederen is deze redenering echter niet van toepassing. Een lagere productie van intermediaire goederen in een beperkt aantal landen betekent dat het aantal inputs voor de productie in andere landen afneemt. Door dit negatieve aanbodeffect neemt ook de productie af in landen die geen strenge regelgeving hebben geïmplementeerd. In de praktijk zullen bovenstaande effecten allemaal in meer of mindere mate van toepassing zijn op de vraag of carbon leakage nu negatief dan wel positief is.

Tenslotte vinden we dat internationaal bezit van productiefactoren, bijvoorbeeld in de vorm van buitenlandse investeringen, ook een rol speelt in hoeverre non-coöperatief milieubeleid tot efficiënte uitkomsten leidt. Als landen in hoge mate afhankelijk zijn van buitenlandse investeringen, dan zal een gedeelte van de kosten van milieubeleid direct ten deel vallen aan buitenlandse eigenaren. In een dergelijk geval neemt de prikkeling van lokale overheden om een strenger milieubeleid te implementeren toe. Immers, men kan wel rekenen op de baten van een strenger milieubeleid, maar niet de kosten. Wanneer een dergelijke prikkeling in alle landen aanwezig is, omdat landen wederzijds een aanspraak doen op binnenlandse productiefactoren, dan zal milieubeleid de facto strenger uitvallen. Dit hoofdstuk laat dus zien dat verschillende facetten van globalisering ervoor kunnen zorgen dat internationale handel, in een wereld waarin non-coöperatief milieubeleid nog steeds het uitgangspunt is, niet per se hoeft te leiden tot een race-to-the-bottom met alle gevolgen voor milieukwaliteit van dien.

In het laatste hoofdstuk van deze thesis staan we wederom stil bij de relatie tussen handel, groei en het milieu. Een belangrijk concept is dat van de "environmental Kuznets curve". Dit verband, voor het eerst gevonden door Grossman and Krueger (1993, 1995), stelt dat er een omgekeerde U-relatie bestaan tussen inkomen enerzijds en milieuvervuiling anderzijds. Grossman and Krueger (1993, 1995) vonden dus dat milieuvervuiling eerst lijkt toe te nemen met de hoogte van het inkomen per hoofd van de bevolking maar dat, na mate het inkomen een bepaalde drempelwaarde bereikt, milieuvervuiling juist afneemt bij een verdere toename van het inkomen per hoofd van de bevolking. Economen hebben zich intensief bezig gehouden met de vraag in hoeverre het hier een universele relatie betreft en hoe deze relatie kan worden verklaard.

In dit hoofdstuk stellen we een simpel analytisch model op waarin we ons bezig houden met de vraag in hoeverre deze relatie wordt beïnvloedt als we rekening houden met het feit dat landen met elkaar in verband staan via internationale handel. We baseren ons model op dat van Acemoglu en Ventura (2002). Acemoglu en Ventura (2002) tonen aan dat rijke landen langzamer groeien dan arme landen. De reden hiervoor is eenvoudig. Een rijk land zal een relatief grote hoeveelheid intermediaire goederen proberen te verkopen op de wereldmarkt en via de wet van vraag en aanbod daarvoor een relatief lage prijs ontvangen. Deze relatief lage prijs vertaalt zich weer in een relatief lage rentevoet, waardoor de prikkel tot sparen in rijke landen relatief laag is. Wij breiden dit model uit door het toevoegen van milieuvervuiling in de productie van intermediaire goederen, de mogelijkheid tot het opruimen van vervuiling door bedrijven en een rol voor milieubeleid door overheden.

Uit onze studie blijkt onder meer dat er weinig reden is om een unieke relatie tussen inkomen enerzijds en milieuvervuiling anderzijds te verwachten. Deze relatie hangt onder meer af van de initiële verdeling van het inkomen tussen de verschillende landen. Dit gegeven kan verklaren waarom onderzoekers, na het initiële enthousiasme dat volgde op het onderzoek van Grossman en Kruger (1993, 1995), zoveel moeite hebben ondervonden bij het vinden van eenduidige relatie tussen de hoogte van het inkomen en de mate van milieuvervuiling. Ook vinden we dat, afhankelijke van de initiële inkomensverdeling, er situaties mogelijk zijn waarin de vervuiling in arme landen nog steeds toe neemt, terwijl hij in rijke landen al af neemt. Eveneens bestaat er de mogelijkheid dat arme landen een nadeel ondervinden in de zin dat zij eerder, in termen van inkomen, een streng milieubeleid dienen te implementeren. De reden hiervoor is dat arme landen "opgroeien" in een wereld die gekenmerkt wordt door een verslechterde toestand van het milieu. Terwijl vervuiling slechts een kleine rol speelde ten tijde van de industriële revolutie in de 19e eeuw, en de westerse landen daarom geen prikkel hadden om vroegtijdig een streng milieubeleid te voeren, is de situatie vandaag de dag radicaal anders. Landen als India en China, die pas zeer recent een lange periode van hoge economische groei doormaken, worden al vroegtijdig geconfronteerd met (wereldwijde) milieuproblematiek. Het model laat eveneens de mogelijkheid zien dat het soms efficiënt is om eerst in industrieën die blootstaan aan internationale handel te beginnen met milieubeleid in plaats van niet-verhandelbare sectoren. Dit hangt af van de prijselasticiteit van de vraag naar verhandelbare goederen, evenals de omvang van deze sector in de gehele economie. Als de verhandelbare sector relatief klein is in omvang ten opzichte van de niet-verhandelbare sector, kan het optimaal zijn om eerst daar strenger milieubeleid te implementeren, omdat de totale kosten voor de maatschappij dan lager uitvallen.

Discussie

Er zijn verschillende richtingen voor toekomstig onderzoek die kunnen voortbouwen op het onderzoek in deze thesis. We noemen hier enkele mogelijkheden. Om het een en ander inzichtelijker te maken, stroomlijnen we deze discussie aan de hand van twee thema's, te weten (1) Internationale handel, economische groei en het milieu (hoofdstuk 3 en hoofdstuk 6) en (2) Wederzijdse afhankelijkheden tussen landen en het milieu (hoofdstuk 2, hoofdstuk 5 en hoofdstuk 6).

Deel 1. Internationale handel, economische groei en het milieu.

Ten eerste, we hebben geen aandacht geschonken aan transitiedynamiek in een Hecksher-Ohlin omgeving. Het studeren van transitiedynamiek in een H-O omgeving is geen gemakkelijke opgave. Zeer recent is Caliendo (2010) erin geslaagd om een volledige karakterisering te geven van de transitiedynamiek in een Hecksher-Ohlin model met twee productiefactoren, twee goederen en twee landen. Het zou mogelijk moeten zijn om op dit werk voort te bouwen en zo in meer detail de relatie tussen international handel, economische groei en milieuvervuiling te analyseren.

Ten tweede, in hoofdstuk 3 nemen we aan dat er slechts twee productiefactoren zijn, kapitaal en vervuiling. Ook veronderstellen we dat beide factoren niet constant zijn. Een bezwaar tegen onze aannames van slechts twee productiefactoren zit in de evenwichtsresultaten die zijn verkregen in hoofdstuk 3. We vinden dat alle evenwichtsuitkomsten, inclusief wereldwijde vervuiling, enkel afhangen van paramaters gerelateerd aan technologie en voorkeuren, maar niet van voorraden van schaarse productiefactoren. Omdat in werkelijkheid de natuurlijke hulpbronnen op aarde eindig zijn, lijkt het aannemelijk dat deze op een of andere manier een invloed moeten hebben op de evenwichtsuitkomsten in het model. Het introduceren van arbeid of land is een eerste mogelijke stap om deze kritiek tegemoet te komen.

Ten derde, hoofdstuk 3 maakt gebruik van een interessante maar ingewikkelde veronderstelling dat alle agenten hun beslissingen baseren op alle toekomstige ontwikkelingen. Dit betekent dat beleidsmakers het hele toekomstige pad van emissies, nationaal inkomen, prijzen etc. kunnen voorzien en berekenen om zo optimale beslissingen in het heden te maken. Om het model dan volledig te kunnen karakteriseren, moeten we de hele distributie van economische activiteit over de twee landen weten voor elke mogelijke actie. Deze veronderstelling is een van de redenen waarom een volledige karakterisering van ons model ontbreekt. In een recent onderzoek op het terrein van dynamiek in ruimtelijke economische modellen, laten Desmet and Rossi-Hansberg (2010) zien dat een mogelijke oplossing voor dit probleem ligt in het opleggen van 'voldoende structuur'. Dit moet er dan voor zorgen dat de (meeste) agenten, dat wil zeggen, de producenten, consumenten en beleidsmakers, feitelijk alleen beslissingen maken met het oog op het heden. Met andere woorden, hun beslissingen worden alleen beïnvloedt door determinanten in het heden. In hoofdstuk 6 hebben we aangenomen dat agenten ook zulke 'statische beslissingen' nemen ten aanzien van het milieubeleid, maar dit was een veronderstelling en geen uitkomst. Hoe dan ook, er zijn wellicht betere manieren om statische besluitvorming te introduceren. In ieder geval moet een dergelijk aanpak resulteren in een model waarin de kosten en baten van milieubeleid niet direct afhangen van toekomstige variabelen.

Ten vierde, dynamische handelsmodellen zouden ook kunnen profiteren van een meer realistische visie op milieutechnologieën. In hoofdstuk 6 nemen we bijvoorbeeld aan dat de milieutechnologie onderhevig is aan toenemende schaalopbrengsten. Dit betekent dat op de lange termijn alle landen relatief probleemloos een volledige schone technologie kunnen implementeren. In de praktijk is het waarschijnlijk dat schonere productietechnologieën de uitkomst zijn van langere perioden van onzekere investeringen in fundamenteel en toegepast onderzoek. Het zou interessant kunnen zijn om technologische vooruitgang in ons model te introduceren die in essentie de uitkomst is van een kansspel. Op vergelijkbare wijze zou men kunnen werken aan het idee dat enkel landen die voldoende dicht tegen de kennisgrens aanzitten de capaciteit hebben om schonere productietechnologieën uit te vinden en te ontwikkelen. Dit zou betekenen dat milieutechnologie zich relatief traag ontwikkelt in een wereld met een scheve inkomensverdeling. Dit zou nieuwe inzichten kunnen opleveren ten aanzien van de relatie tussen ongelijkheid, milieutechnologie en milieukwaliteit.

Tenslotte, een laatste mogelijke richting voor toekomstig onderzoek vindt zich in het opzetten van theorieën die ruimte bieden voor meerdere evenwichten, waaronder evenwichten met armoedevallen en milieuvallen, terwijl deze modellen nog steeds ruimte geven aan handel, de initiële inkomensverdeling en het beheer van natuurlijke hulpbronnen om de uitkomsten te bepalen. Een potentieel begin om aan dergelijke modellen te werken, wordt gegeven door Chamon en Kremer (2009). Net als Acemoglu en Ventura (2002) zijn zij geïnteresseerd in het verklaren van de lange termijn inkomensverdeling tussen landen. In tegenstelling tot het model van Acemoglu en Ventura (2002) geeft hun model echter geen garantie op succes. De mogelijkheid voor een arm land om zich te ontwikkelen tot een ontwikkeld land hangt mede af van zijn exportmogelijkheden. Hoe groter de groep van rijke landen, des te makkelijker wordt het voor arme landen om te exporteren en dus zich te kunnen ontwikkelen. Hun model laat zien dat als verschillen in bevolkingsgroei tussen ontwikkelde en ontwikkelingslanden te ver uiteen lopen dat dan vooruitgang in een groot deel van de derde wereld tot een halt kan komen. Een dergelijk raamwerk zou ook inzichten kunnen bieden op het terrein van duurzame groei. Misschien zou men kunnen laten zien hoe te lange periodes van armoede en hoge bevolkingsgroei de kans vergroot dat men evenwichten bereikt die niet duurzaam zijn of waar er zelfs sprake is van een ecologische catastrofe.

Deel 2. Wederzijdse afhankelijkheden tussen landen en het milieu

Een van de meest interessante bevindingen in hoofdstuk 5 is wellicht dat bepaalde aspecten van globalisering, te weten verticale integratie van de wereldeconomie alsmede internationaal bezit van productiefactoren, de negatieve effecten van free-riding op de wereldwijde milieukwaliteit kunnen compenseren. Het model dat gebruikt werd in hoofdstuk 5 had enkele bijzondere veronderstellingen, waarin sommigen slechts werden gemaakt uit de noodzaak om tot analytische resultaten te komen. Andere aannames zijn wellicht essentiëler voor de uitkomsten. Om de gevoeligheid van onze resultaten te analyseren, zouden we ons kunnen richten op het verwerken van de volgende veronderstellingen: meerdere productiefactoren, handel in intermediaire goederen en handel in eindgoederen voor consumptie, toenemende schaalopbrengsten onder monopolistische competitie en asymmetrische landen.

Een andere richting voor toekomstig onderzoek betreft de toenemende ongevoeligheid van lokaal milieubeleid. In hoofdstuk 5 hebben we uitgelegd dat sommige aspecten van globalisering misschien kunnen leiden tot een situatie waarin lokale milieuvervuiling ongevoeliger wordt voor lokaal milieubeleid. Meer in het algemeen, globalisering zou er voor kunnen zorgen dat er situaties ontstaan waarin de lokale milieukwaliteit in steeds minder mate wordt bepaald door lokale determinanten. Let wel, deze observatie is niet gebaseerd op het concept van grensoverschrijdende milieuvervuiling en moet eveneens niet gezien worden als een triviale constatering. Om dit beter te kunnen begrijpen, moeten we een blik werpen op een gerelateerd concept, dat van factor insensitiviteit, dat recentelijk weer in de belangstelling staat in de literatuur over internationale handel.

Een oude maar belangrijke vraag in de theorie van de internationale handel luidt hoe de prijzen van productiefactoren worden bepaald in een wereld met internationale handel en, meer in het bijzonder, hoe gevoelig deze prijzen zijn voor verandering in het lokale aanbod van productiefactoren. Een bekend uitgangspunt is dat van complete factor insensitiviteit; in het standaard Hecksher-Ohlin model zijn de prijzen van productiefactoren zoals arbeid en kapitaal volledig ongevoelig voor veranderingen in het aanbod van lokale productiefactoren, mits er sprake is van incomplete specialisatie en prijzen voor productiefactoren in alle landen aan elkaar gelijk zijn. Deze ongevoeligheid van de prijzen van productiefactoren gaat niet meer op onder meer algemene aannames met betrekking tot handelskosten en marktstructuur. Zeer recent hebben Trefler and Zhu (2010) en Burstein and Vogel (2011) dit resultaat opnieuw onder de loep genomen in modellen met een input-output structuur voor productie en handelskosten. Op vergelijkbare manier zou hun onderzoek als inspiratie kunnen dienen om een gerelateerde vraag te kunnen beantwoorden: door wat voor factoren worden lokale milieukwaliteit en de prijzen van natuurlijke hulpbronnen bepaald in een wereld waar handelskosten en input-output structuren een grote rol spelen? Voortgang op dit terrein zou niet alleen licht kunnen werpen op meer specifieke vragen, zoals de mate van carbon leakage, het zou eveneens voor een meer solide fundering kunnen zorgen voor de recente opleving van de empirische input-output analyse in het vakgebied van de ecologische economie. Onderzoek op dit terrein zou ook nieuwe inzichten kunnen opleveren als het gaat om het toerekenen van de bijdrage van de verschillende productiesectoren aan de uitstoot van broeikasgassen in een wereld met internationale handel.